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Use of byproducts in forage-based, post-weaning beef systems and effects of serial slaughter on performance and profitability

Robert G. Bondurant Jr.
University of Nebraska-Lincoln, robby.bondurant@unl.edu

USE OF BYPRODUCTS IN FORAGE-BASED, POST-WEANING BEEF SYSTEMS AND EFFECTS OF SERIAL SLAUGHTER ON PERFORMANCE AND PROFITABILITY

by

Robert Gregory Bondurant Jr.

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Use of byproducts in forage-based, post-weaning beef systems and effects of serial slaughter on performance and profitability

Robert G. Bondurant Jr., Ph.D.

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Advisor: James C. MacDonald

Crude glycerin was included in high-forage beef growing diets at 0, 4, 8, and 12% diet DM to determine the effect on fiber digestion by evaluating changes in microbial species abundance, NDF digestibility, and VFA concentrations. Total tract NDF digestibility decreased with increasing inclusion of GLY in high-forage diets. However, there was no decrease in *in situ* NDF digestibility and *Fibrobacter succinogenes* microbial populations were unaffected, indicating that fiber digestion was not directly affected by inclusion of GLY. Acetate decreased while propionate and butyrate VFA proportions increased as GLY increased.

Spayed heifers were utilized in a 2-yr study to evaluate the effect of increasing amounts (**LOW, MED, HIGH**) of modified distillers grains plus solubles (**MDGS**) supplementation during a winter corn residue grazing phase. Supplementing increasing amounts of MDGS during winter residue grazing supplies adequate protein and additional energy for gain. Finishing performance was not affected by winter supplementation amount when heifers were backgrounded on summer range. If summer grazing conditions are not limited, HIGH supplementation during the winter can increase HCW by 16 kg. An increase of 16 kg in HCW can increase carcass revenue by $75.98 which can offset added costs of winter supplementation.

Steers were fed 0, 22, or 44 d longer than the industry average live marketing endpoint to determine the effect of DOF on performance and profitability when marketed on a grid basis. As DOF increased, live and carcass-based performance (ADG, G:F) decreased. However, HCW increased by 14 and 36 kg as steers were fed an additional 22 and 44 DOF, respectively. As DOF increased, 12^{th} rib fat thickness and YG linearly increased while marbling score was not different. Total feedlot costs and discounts per steer for YG and overweight carcasses linearly increased as DOF increased for all profitability analyses. However, revenue generated from HCW increased which minimized economic losses when evaluating steer profitability using a 5-yr market average. When feeder price was higher than dressed price, increasing DOF for steers minimized losses. When evaluating high corn price, profitability was decreased as DOF increased. Contrarily, when corn price was low, profitability was improved by increasing DOF.

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Glycerin production and composition

The demand for alternate fuel and energy sources has increased in the past decade. One of the potential sources of alternative energy is biodiesel. During the production of biodiesel, co-products such as crude glycerin are created. Glycerin, also known as glycerol or glycerine, is a colorless, odorless, viscous, water-soluble liquid with a slightly sweet taste (ASAIMSEA, 2007). Crude glycerin is composed of the glycerol backbone of the triglyceride in addition to impurities (water, free fatty acids, residual catalyst, salts, and methanol) from the biodiesel production process. The capacity for refining glycerin to human-grade products cannot keep pace with biodiesel production, thus the by-product formed remains in the crude form containing impurities.

Crude glycerin can be produced through hydrolysis, transesterification, or synthetically. Hydrolysis and transesterification utilize the same method of combining a lipid source (animal fat or vegetable oils) with a catalyst (usually sodium hydroxide) and with fatty acids (hydrolysis) or methanol (transesterification). Glycerin produced from transesterification (biodiesel production) is one of two parts derived from the reaction of a lipid source and methanol. During the process, the bonds on the triglyceride molecule holding the three carbon glycerol backbone and the fatty acid strands together are severed. The fatty acids bond with the alcohol (methanol) to produce methyl esters of fatty acids (biodiesel), excess methanol is removed from the glycerin residue and the result is crude glycerin which contains approximately 85% glycerin, 10% water, 4% salt, less than 0.5% methanol, and around 0.5% free fatty acids (ASAIMSEA, 2007).

Concentration of residues in crude glycerin can vary greatly due to production practices such as alcohol and catalyst used during transesterification and extent of methanol extraction. The use of either sodium or potassium chloride as the catalyst can cause fluctuations in crude glycerin composition. Thompson and He (2006) evaluated the effect of seven oils and methanol on crude glycerin in transesterification production. Thompson and He (2006) determined there was little variation in chemical and physical properties among oil sources. Carbon content averaged 25% for all oils and protein ranged from 0.06 – 0.44% while fat ranged from 1-13% and carbohydrates varied from 75-83% (DM basis). Gott (2009) evaluated 16 samples from 9 different vendors throughout the Midwest. There was an apparent difference in color and viscosity as well as pH which averaged 8.25 and varied from 5.55-12.36. Ash concentration averaged 4.79% and fluctuated from 1.28-8.98% while the ethyl alcohol concentration was < 10 ppm. Methanol concentration throughout samples varied greatly depending on production methods. Gott (2009) also noted that moisture had the greatest amount of variation, with an average of 6.12% moisture. Concentration of both fatty acids and glycerol were not different among samples, and average glycerol concentration was 30.5%. However, Gott did not report sodium content of these samples analyzed.

Title 21, Code of Federal Regulations, Section 582.1320 deems that glycerin is a generally recognized as safe animal feed ingredient. This regulation is defined for refined glycerin which typically comes from saponafication. The U.S. Food and Drug administration (FDA) has issued a letter stating that glycerin from biodiesel should meet the U.S. Pharmacopeia standards for glycerin, which includes a limit of 150 mg/kg of methanol, and FDA would consider such glycerin with higher methanol limits as unsafe for feeding to animals (Sellers, 2008). Biodiesel plants which render crude glycerin with methanol contents greater than 150 mg/kg will not have access to the livestock feeding industry due to regulations.

Rumen fermentation of crude glycerin

In beef cattle, the rumen is comprised of a microbial population containing bacteria, fungi, and protozoa. Each of these species of microorganisms plays a role in digesting feed consumed by the animal. In the case of glycerin, the major bacteria responsible for fermentation are not yet defined. Stewart et al. (1997) describe *Megasphaera elsdenii, Streptococcus bovis,* and *Selenomonas ruminantium* as the bacteria responsible for the fermentation of glycerol and increases in butyric acid are due to *Megasphaera elsdenii* populations. Several other researchers using continuous culture fermenters have measured decreases in *Butyrivibrio fibrisolvens* and *Selenomonas ruminantium* while having no effect on *Ruminococcus albus* or *Succinivibrio dextrinosolvens* bacterial populations as glycerin concentration increased (Abo El-Nor et al., 2010 and AbuGhazaleh et al., 2011). However, these results describing bacterial populations responsible for glycerin fermentation are not definitive due to difficulties in identifying and quantifying rumen microbial populations. Although rumen microbial identification proves difficult, the data are conclusive that increasing concentrations of crude glycerin in beef cattle diets results in increased propionate and butyrate production at the expense of acetate production.

Hales et al. (2013b) evaluated rumen fermentation characteristics of diets containing 0, 2.5, 5.0, and 10% crude glycerin as a % of diet DM. As glycerin inclusion increased in diets, molar proportions of propionate, butyrate, and valerate increased ($P < 0.05$). Consistent with previous research, molar proportions of acetate decreased as glycerin concentration increased ($P < 0.05$). With the increase in propionate and decrease in acetate, the A:P ratio decreased ($P < 0.01$). Diets including glycerin showed decreased concentrations of isovalerate compared to the control ($P < 0.05$).

Abo El-Nor et al. (2010) and AbuGhazaleh et al. (2011) evaluated the effect of increasing levels of glycerin on rumen fermentation and bacteria in continuous culture fermenters. As glycerin inclusion increased, molar proportions of propionate, butyrate, valerate, and isovalerate increased while acetate proportions decreased ($P < 0.05$). Concentrations of *Butyrivibrio fibrisolvens* and *Selemononas ruminantium* decreased with higher concentrations of glycerin inclusions ($P < 0.05$) while there was no difference in *Ruminococcus albus* and *Succinivibrio dextrinosolvens*. Wang et al. (2009) also described increases in ruminal propionate concentrations with decreases in acetate yielding a reduction in acetate to propionate ratio.

VFA absorption

Propionate produced through fermentation of glycerol by bacteria is available to the animal to be utilized for energy. However, propionate is in the form of a volatile fatty acid of which 95% is absorbed across the rumen wall and a small portion (< 5%) reaches the gastrointestinal tract. There are four methods of VFA absorption for ruminants: passive diffusion, bicarbonate dependent, nitrate dependent, and electrogenic transport (Penner, 2014). Longer chain VFA such as butyrate will absorb more rapidly than a smaller chain VFA such as acetate.

The rumen has a pH that can range from 5.5 for concentrate diets to 6.5 for forage diets, where VFA have an average pKa of 4.8. Since the pKa of VFA is lower than the rumen pH, the majority of propionate will be in the dissociated form (negative charge, no H+) with a small amount in the undissociated form (neutral charge, contains H+). This is important because only VFAs in the undissociated form can freely diffuse across the rumen wall meaning only the small proportion in the undissociated form will diffuse without an added energy cost. As rumen pH decreases, the amount of undissociated VFA increases and thus, absorption across the rumen wall increases via passive diffusion. Volatile fatty acids freely move into the epithelial cells of the rumen papilli where it dissociates and can then freely pass through a voltage gate channel in the basolateral membrane into the portal blood supply. The major limitation to passive diffusion is that the majority of VFA are dissociated in the rumen.

The majority of VFA will be absorbed via bicarbonate dependent transport through an anionic exchange channel located in the brush border membrane. The dissociated VFA will be exchanged with a bicarbonate across the membrane allowing for bicarbonate to enter the rumen (allows for buffering of pH) and dissociated VFA to enter the epithelial cell. The dissociated VFA can then pass through the basolateral membrane via another anionic exchange of bicarbonate in the portal blood supply. Using carbonic anhydrase, the epithelial cell can also convert water and carbon dioxide to carbonic acid which can produce bicarbonate. All of these processes utilize the movement of bicarbonate through the portal blood supply, epithelial cells, and rumen allowing for absorption of VFA and buffering capacity.

Nitrate sensitive transport is similar to bicarbonate dependent transport because the process utilizes an anionic exchange channel located in the brush border membrane. Nitrate located in the epithelial cell is exchanged for a dissociated VFA. The process for the dissociated VFA to enter the portal blood supply is consistent with previous descriptions. The nitrate, which is in the rumen, however can be converted to ammonia and utilized by the microbial population. This nitrate will ultimately end up as microbial amino acids (**AA**) which the animal can utilize.

The process of VFA absorption causes an increase in H+ concentration within the epithelial cells. These H+ ions are exposed of or utilized through multiple pathways. Bicarbonate can bind with H+ to produce carbonic acid which can produce water and carbon dioxide. The H+ can also be transported into the rumen via energy dependent H+ pumps located in the brush border membrane. The third method to dispose of H+ ions in the epithelial cells is sodium exchange channels located in the basolateral membrane. The sodium from the portal blood supply is exchanged with a H+, however sodium concentrations increase in the epithelial cells. Sodium must then be transported out of the epithelial cell through a sodium-potassium pump which requires energy.

Propionate VFA metabolism

Propionate is the only gluconeogenic VFA which can provide 30–65% of the glucose for a ruminant with the remainder of the glucose coming from amino acid deamination in the liver (Stewart et al., 1997). Of the propionate produced in the rumen, 95% enters the portal blood supply and travels to the liver where it enters the TCA cycle.

Propionate is converted to propionyl-CoA which reacts with carbon dioxide and carboxylase to produce methymaloyl-CoA. Methyaloyl-CoA undergoes an isomerase reaction and enters the TCA cycle as succinyl-CoA. Because succinyl-CoA production comes in the TCA cycle after the losses of carbon from the conversion of isocitrate to alpha ketoglutarate and alpha ketoglutarate to succinyl-CoA, propionate can enter the TCA cycle and not lose carbon. The succinyl-CoA will then continue through the TCA cycle to oxaloacetate and then through gluconeogenesis.

Propionate contains three carbons where glucose contains six carbons. The utilization of two propionate molecules through gluconeogenesis can produce a glucose molecule for the animal to use as energy. This production of glucose coupled with no energetic loss of carbon to methane and CO_2 (Boadi et al., 2004) allows propionate to be the most energetically favorable VFA produced in ruminants. Thus, methods such as feeding glycerin to increase production of propionate in the rumen are utilized in both grain and forage-based diets and evaluated to measure animal efficiency.

Crude glycerin use in livestock

The expansion of the biodiesel industry has caused an increase in the availability of crude glycerin and thus its possible use as an animal feed ingredient. A significant amount of research has previously been conducted in species such as poultry, swine, sheep, dairy and beef cattle. Substantial effort has been placed on determining the feeding value of crude glycerin in each of these species as well as any adverse effects it may have on subsequent performance.

Apparent metabolizable energy (**AME**) of glycerin for broiler chickens was evaluated by Dozier et al. (2008) by feeding 0, 3, 6, and 9% glycerin in three experiments. The AME average for all experiments was 3,434 kcal/kg, similar to gross energy. Lammers et al. (2008a) evaluated crude glycerin in laying hen diets to determine AME by feeding 0, 5, 10, and 15% crude glycerin. Glycerin inclusion level had no effect ($P > 0.10$) on egg production rate, egg weight, egg mass, or feed consumption. Apparent ME was determined by linear regression to be 3,805 ± 238 kcal/kg. Crude glycerin level's effect on laying hen's egg performance and nutrient utilization was evaluated by feeding 0, 2, 4, and 6% crude glycerin substituted for corn starch (Swiatkiewicz and Koreleski, 2009). Glycerin inclusion rate had no effect on performance (egg production, weight, mass, daily feed consumption, and feed conversion. The AME for crude glycerin was determined by linear regression at 3,970 kcal/kg (as-is basis). These results suggest that glycerin can be incorporated into poultry diets to meet ME requirements without any adverse effects on hen or egg performance.

Lammers et al. (2008b) determined apparent digestible energy (DE) and metabolizable energy (ME) for growing pigs utilizing 4 experiments containing varying levels of crude glycerin. Digestible energy was determined to be 3,344 ± 8 kcal/kg and ME was determined to be 3,207 ± 10 kcal/kg which suggests that crude glycerin is an effective source of energy for growing pigs. Origin source of crude glycerin was evaluated in nursery pig diets to determine DE and ME content (Kerr et al., 2009). Kerr noted gross energy, DE, and ME to be 4,325, 4,457 and 3,682 kcal/kg, respectively compared to corn, which contained 4,510, 3,525 and 3,420 kcal/kg, respectively (NRC, 1998). The ME for crude glycerin averaged 85.4% of its gross energy in which glycerin source had no effect. Shields et al. (2011) also determined the nutritional value of crude glycerin in nursery pigs. Replacing lactose in basal starter diets with 10% glycerin improved ADG (266 vs. 191 g/day, $P = 0.01$) and G:F (871 vs. 679 g/kg, $P = 0.01$) compared to the control containing 0% crude glycerin. It is apparent that glycerin can be utilized in pig diets to meet DE and ME requirements while also observing an increase in ADG and G:F.

Musselman et al. (2008) evaluated the effects of crude glycerin on feedlot performance and carcass characteristics for market lambs utilizing 0, 15, 30, and 45% glycerin, which replaced corn in the diets. Lambs fed 0 and 15% glycerin had greater DMI ($P < 0.001$), ADG ($P < 0.001$), and G:F ($P < 0.001$) with fewer days on feed to finishing ($P < 0.001$) compared to 30 and 45% glycerin diets. No differences were detected for final BW, HCW, LM area, body wall thickness, flank streaking, or leg score for treatments. Diets containing 0 and 15% glycerin also had significantly greater dressing percentage ($P = 0.01$), 12th rib fat thickness ($P = 0.02$), and YG ($P = 0.03$) compared with 30 and 45% glycerin diets. Lambs fed diets containing 30 or 45% glycerin tended to have increased LM area ($P = 0.09$). Live growth and carcass characteristics for finishing wether lambs were evaluated utilizing 0, 5, 10, 15, and 20% glycerin diets

(Gunn et al., 2010a). A linear increase (P = 0.04) for DMI, a quadratic effect for ADG (P = 0.05), and a quadratic tendency (P = 0.06) for G:F to increase was noted as crude glycerin level increased during the first 14 days of feeding. No differences were detected for final BW, DOF, cumulative DMI, cumulative ADG, and cumulative G:F among treatments. There were no differences observed for carcass traits. Gunn et al. (2010b) evaluated the effects of increasing levels of crude glycerin on feedlot performance, carcass characteristics, and serum metabolite and hormone concentrations on ewe and wether lambs. Dietary treatments consisted of 0, 15, 30, and 45% inclusion of crude glycerin. A linear increase in DOF (P < 0.01), quadratic decrease in ADG (P = 0.02), and linear decreases in DMI and G:F (P < 0.01) were noted as glycerin concentration increased. No significant effect was observed for HCW and LM area, but dressing percentage, 12th rib fat thickness, and LM ether extract decreased linearly with increasing level of glycerin ($P \leq 0.02$). The data from these experiments suggest that crude glycerin can be fed in lamb finishing diets up to 15% replacing corn with no adverse effects on performance or carcass characteristics.

Carvalho et al. (2011) compared diets replacing 11.5 and 10.8% (pre and postpartum, respectively) high moisture corn with glycerol to transition diets containing 0% glycerin for dairy cows. Carvalho et al. (2011) noted no difference in either prepartum or postpartum feed intakes by feeding glycerin. Milk composition, yield, urea nitrogen, somatic cells, and energy balance were unchanged by the inclusion of glycerin. A decrease in blood glucose during the prepartum period was noted for glycerin diets (P < 0.05). There was no response of blood metabolites for the postpartum period, when glycerin was fed as compared to 0% glycerin diet. Total rumen VFA production was unaffected by treatment, but proportions of VFAs were different. A shift from acetate to propionate concentration was noted for glycerin fed cows vs. cows fed 0% glycerin. The concentration of butyrate (15.3 vs 11.5%) was also high for cows fed glycerin versus cows fed 0% crude glycerin, respectively. Donkin et al. (2009) evaluated crude glycerin as a replacement of corn grain in lactating dairy cows by replacing 0, 5, 10, and 15% corn with glycerol. No significant effect was noted for milk production, composition, or feed intake across treatments. Glycerol inclusion decreased milk urea nitrogen. Cows fed 10 and 15% glycerin diets gained more BW than 0 and 5% GLY, but body condition score was unaltered. These data suggest that glycerol can replace up to 15% of diet DM of corn grain without any undesirable changes in milk production or composition.

Literature pertaining to the effects of crude glycerin on beef cattle performance or carcass characteristics has proven variable due to glycerin concentrations evaluated or dietary ingredients with which the glycerin replaced. Parsons et al. (2009) reported a decrease in DMI ($P < 0.01$), 12th rib fat ($P = 0.05$), and marbling scores ($P = 0.02$) as glycerin concentration increased in steam-flaked corn (**SFC**)-based finishing diets. However, ADG and G:F increased with increasing glycerin concentration up to 8% (DM basis). Moore et al. (2011) reported a linear increase in final BW, DMI, ADG, G:F, and HCW for steers fed varying levels of crude glycerin in a SFC-based finishing diet. Using 0 and 10% crude glycerin in finishing diets containing grain vs. co-product, Pyatt et al. (2007) reported treatment differences for cattle fed finishing diets replacing corn with 0 or 10% crude glycerin. While glycerin inclusion in grain diets increased ADG of steers by 11.4%, glycerin inclusion in diets containing 30% dried distillers grains plus solubles (**DDGS**) had an increase in ADG of 2.5%. Feeding glycerin diets reduced DMI by 10.1% (P < 0.05) with a greater decrease in DMI for co-product diets vs. grain diets (11.8% vs. 8.1%, respectively). Inclusion of glycerin increased G:F here and throughout the feeding period by 19.2% (P < 0.05). Overall, feeding glycerin in high-concentrate diets resulted in a 21.9% improvement in G:F and a 16.4% improvement when glycerin was included in co-product diets. A more recent study conducted by Hales et al. (2015) evaluated 0, 5, 10, and 15% glycerin in finishing diets and its subsequent effects on energy metabolism and nutrient balance. Based on digestion data, increasing concentrations of crude glycerin in the diet tended to linearly decrease fecal energy loss while DE tended to increase ($P \leq$ 0.07), with no impact on urinary loss. Glycerin inclusion caused a decrease in retained energy and an increase in N loss ($P \leq 0.07$). With the results from these studies, crude glycerin can be used effectively in grain-based finishing diets.

Limited data are available for the effects of crude glycerin inclusion in growing beef diets, more importantly the impact of glycerin on fiber digestion. Performance on early-weaned beef calves fed diets containing crude glycerin suggested calf performance equal to or greater than that of diets containing no glycerin (Gunn et al., 2011). In the study by Hales et al. (2013b) evaluating 0, 2.5, 5, and 10% glycerin inclusion in receiving diets, steers had decreased DMI but increased G:F ($P \leq 0.07$). The response in G:F is likely due to the reduction in acetate and increase in propionate as discussed previously. Propionate can enter the TCA cycle through conversion to succinyl-CoA and undergo gluconeogenesis to produce glucose for the animal to utilize. Hales et al. (2013a) evaluated glycerin inclusion in SFC-based growing diets. The first trial evaluated 0, 2.5, 5, 7.5, and 10% glycerin inclusion replacing SFC in the diet and the authors determined 7.5% inclusion was optimal with ending BW and ADG increasing quadratically ($P \leq 0.07$). To evaluate the impact of replacing an energy or a fiber source, either SFC or alfalfa hay was replaced with glycerin at 7.5% dietary DM and compared to a negative control. Hales et al. (2013a) reported diets with glycerin replacing alfalfa had a greater impact compared to replacing SFC. The diet with glycerin replacing SFC had similar performance as the control. These data suggest that crude glycerin has a feeding value greater than alfalfa hay but less than that of SFC in growing diets and can replace a fiber source at 7.5% to increase animal performance. However, the true effect of glycerin inclusion on fiber digestion is unknown.

Use of Distillers Grains Supplementation in Long-Yearling Beef Systems

Beef Production Systems

Available resources and the decision to retain ownership of calves can have a major impact on the production system with which producers choose to utilize within the beef industry. Feed cost, which can include grass, crop residue, supplement or a ration, has the greatest impact on system profitability accounting for approximately two-thirds the total cost of beef production (Anderson et al., 2005). One method to decrease total feed cost is to utilize forages and convert that forage into gain. In the beef industry, this management strategy is referred to as “backgrounding” and results in two types of cattle available to feeders, calf-feds and yearlings.

The term calf-fed is derived from the age at which the animal enters the feedyard, as a weaned calf anywhere from five to nine months of age. Calf-feds are known to gain slower, eat less, but are 18.7% more efficient over the feeding period and also finish at lighter weights compared to yearlings (Schoonmaker et al., 2002; Griffin et al., 2007; Adams et al., 2010). Days on feed (**DOF**) are greater for calf-feds to reach desired market endpoint which increases the total feed required to finish. Although calf-feds utilize feed more efficiently, the increased total feed cost due to increased DOF can decrease profitability, especially when grain prices are increased (Griffin et al., 2007). The difference in days required to finish a calf-fed versus a yearling is one reason why yearlings become desirable to feeders.

Similar to calf-feds, a yearling derives its name from the age at which it enters the feedyard. A yearling is weaned and backgrounded on either forage or a high-forage growing diet and typically enters the feedyard at twelve months (or greater) of age, hence the name yearling. However, there are several variations to yearlings which can include long and short-yearlings. A short-yearling is younger and has been backgrounded for a shorter period of time (roughly 5 – 7 mo) before placement in the feedyard. A long-yearling is older and has been backgrounded for roughly 10 – 14 mo before feedlot placement. A long-yearling system commonly utilized in Nebraska would include backgrounding on corn stover residue for 5 mo during the winter followed by grazing on either cool season grasses or native range for 5 mo. However, available resources determine which yearling system can be utilized.

Schoonmaker et al., (2002) and Adams et al. (2010) evaluated calf-fed versus yearling steers to determine the effects on feedlot performance and determine if HCW variation and overweight carcasses could be reduced through sorting. Both studies concluded that sorting steers by BW into calf-fed, short yearling, and long yearling groups reduces variation in initial feedlot BW and HCW, ultimately reducing the percentage of overweight carcasses. Griffin et al. (2007) evaluated performance and economics associated with steers which were sorted based on weight in the fall into calf-fed and yearling feeding strategies. The heaviest of the fall calves were managed as calf-feds while the lightest calves were managed as long yearlings. Griffin et al. (2007) reported that yearlings entered the feedlot 143 kg heavier than calf-feds, requiring an average of 78 fewer DOF. Long-yearlings had increased ADG and DMI compared to the calf-feds. Although Griffin et al. (2007) reported an increase in total cost for the yearling, an increase in profitability for yearlings was also due to decreased DOF, which reduces yardage and total feed cost, with increases in sellable HCW. In summary, yearlings are heavier upon feedlot entry, require less DOF, have increased daily DMI but less total DMI, increased ADG, decreased G:F and finish at increased weights compared to calf-feds (Shain et al., 2005; Tatum et al., 2006). However, as HCW increases with utilization of a long-yearling system, there is increased risk for receiving overweight discounts from the packer. One management strategy implemented to overcome overweight discounts is utilization of heifers in a long-yearling system.

Use of Heifers

Due to biological differences, heifers do not gain as fast, have decreased G:F, finish at a lighter weight, and can disrupt normal behavior of other cattle compared to steers (Dinusson et al., 1950; Ray et al., 1969; Cameron et al., 1977; Horstman et al., 1982; Zinn et al., 2008). For these reasons, heifers must be managed differently than steers and are therefore discounted relative to feeder price. Heifers can exhibit estrus, which disrupts other cattle and can also get pregnant. However, these issues can be overcome though the feeding of melengestrol acetate (MGA) or through surgical spaying. The addition of MGA to feed will suppress estrus of heifers and is effective; however, its use will not be discussed in great detail because it is not relevant to the research at hand.

Compared to steers, non-spayed heifers are less efficient due to increased maintenance requirements of the reproductive tract (Garber et al., 1990). Garber stated by surgically removing the ovaries of heifers, the source of estrogen production and reproductive capacity is removed which eliminates the ability to display estrus and become pregnant. Through spaying, heifers have an increased opportunity for maximum growth potential because the energetic requirements of reproduction are no longer in effect. Rupp and Kimberling (1982) developed the most commonly practiced procedure for spaying heifers, which involves vaginal spaying rather than spaying via incision on the flank.

Although spaying heifers reduces management issues dealing with reproduction, it alters the growth rate because their source of estrogen, produced by the ovary, is removed. Garber et al. (1990) evaluated the effect of spaying heifers with and without the use of implants and determined that spayed, non-implanted heifers have decreased performance due to lack of circulating estrogen. In that report, spayed heifers, which received an implant, had increased ADG compared to non-spayed heifers. Similar results to Garber et al. (1990) were reported by Adams et al. (1990) with spayed and intact heifers evaluating feedlot performance when implants were utilized. Adams et al. (1990) reported similar performance between spayed and intact heifers, which were implanted. Sharman et al. (2011) evaluated the effect of spaying heifers on winter, summer, finishing, and carcass performance in an extensive system. Sharman et al. (2011) determined no differences in grazing performance during the winter and summer; however, spayed heifers had increased ADG and G:F during finishing compared to non-spayed heifers. While spaying heifers had no impact on marbling score, HCW, LM area, and YG were increased for heifers which were spayed compared to those which were not (Adams et al., 1990; Garber et al., 1990; Sharman et al., 2011). In summary, surgically spaying and implanting heifers is an efficient method of decreasing energetic costs of reproduction, reducing management needed to avoid pregnancy and disruption to other cattle, and gain improved performance over non-spayed heifers.

Supplementation on Forage

Beef cattle are provided supplements while grazing forages for many reasons such as providing supplemental nutrients, which are deficient in forages, and to improve ADG. Supplementation can save forage, which allows for increased stocking rate and can improve profitability (Rolfe, 2011; Gillespie-Lewis et al., 2016). Since their introduction, by-product feeds have been a valuable feed source to beef cattle to supply additional nutrients such as protein. One byproduct, which is widely used in beef production, is distillers grains plus solubles (**DGS**) from the production of ethanol. Distillers grains have been reported as having energy values equal to or greater than dry-rolled corn, dependent on diet type (forage or grain-based) and DM content of DGS (Oliveros et al., 1989; Ahern et al., 2016). Thus, DGS is a practical option for supplementing calves to provide protein and additional energy when grazing forages.

Several studies have been conducted evaluating the use of DGS supplementation on winter corn residue, summer range, cool and warm season grasses and the effect on animal performance. An analysis of eight grazing studies where DGS was supplemented at either 1.8 or 3.4 kg DM was conducted by Klopfenstein et al. (2007). Klopfenstein determined ADG increased for both levels of DGS, while forage intake was decreased, and feedlot performance was not affected. When supplementing DGS on smooth brome grass pasture, a cool season annual in Eastern Nebraska, MacDonald et al. (2007) determined heifer ADG increased as supplementation of DGS increased. Similarly, Griffin et al. (2012) conducted a meta-analysis of data for increasing DGS supplementation in forage-based diets. Griffin also reported a linear increase in ADG and a quadratic increase in ending BW as DGS supplementation increased. Rolfe (2011) evaluated DGS supplementation on summer range in an extensive beef system and determined steers which were supplemented had increased ADG and greater BW entering the feedlot. Because the summer supplemented steers entered the feedlot at an increased weight, fewer days were required to finish the steers at the same body composition.

Gillespie-Lewis et al. (2016) evaluated two levels of DGS supplementation during winter corn residue grazing and either supplemented 0.6% BW or not during the summer followed by a common finishing ration. In this study, a low level of supplement (0.91 kg DGS daily) was provided to meet only protein requirements and a high level fed to meet protein requirements plus provide additional energy (2.3 kg DGS daily) during the winter. Gillespie-Lewis et al. (2016) observed increased ADG and ending BW for heifers fed the high level of DGS supplementation during the winter. This study demonstrated that supplying an increased amount of DGS to spayed heifers above protein requirements provided additional energy to the animal after MP requirements were met, allowing for increased gain.

Compensatory Gain

The compensatory gain effect allows extensive backgrounding systems to be effectively utilized in the beef industry. The classical description of compensatory gain response is characterized as an accelerated rate of growth after a period of nutritional restriction (Bohman, 1955). It has been hypothesized that increases in intake, and thus energy and protein, after nutritional restriction is the cause for the response of compensatory gain (Taylor, 1959). However, Meyer et al (1965) concluded that independent of intake, energy utilization by the animal was improved during compensatory gain response. The response of compensatory gain has been evaluated in many studies to determine the exact mechanism and quantify the response (Bohman, 1955; Wilson and Osbourn, 1960; Fox et al., 1972, and Drouillard et al., 1991). It appears the response is due to a combination of increased intake, increased protein and energy utilization, and decreased organ weights for calves experiencing compensatory gain. Ultimately, maintenance energy costs are decreased, allowing for increased availability of nutrients for gain.

In a study conducted by Lewis et al. (1990), steers were grown at three rates of gain in the winter to evaluate the effects on summer grazing and subsequent feedlot performance. The study concluded that steer ADG for the summer was decreased 0.81 g for every 100 g increase in winter gain while there were no differences in BW after summer grazing was complete. This is a classic compensatory gain response where the steers that gained the greatest in the winter, gained the least in the summer but all steers ended at the same BW. Similar results were described in the study by Gillespie-Lewis et al. (2016), where the heifers fed 0.91 kg/d DGS (low level) during the winter corn residue grazing period had increased daily gains during the summer grazing period compared to the heifers supplemented 2.3 kg/d DGS (high level) during the winter. However, all heifers in this study performed similar in the feedlot after the compensatory gain response during the summer. These data would suggest that increased winter gains due to increased winter supplementation might not be beneficial if cattle are grazing during the summer before feedlot arrival because feedlot performance is not altered. However, the high winter supplemented heifers in Gillespie-Lewis et al. (2016) had increased HCW after finishing which could provide additional revenue. Careful consideration must be given to the economics of additional supplement cost compared to the increased revenue it generates.

Economics of Long-Yearling Beef Systems

In the beef industry, the purpose of backgrounding can serve many purposes including: 1) increase frame size, 2) increase placement weight, and 3) placement of cattle when market supply of calves is decreased. However, since each backgrounding system is different due to available resources, cattle size, and location, input costs and expected returns must be evaluated to determine profitability of the extensive system.

Several studies have evaluated the use of backgrounding systems and applied economics to the animal performance to determine if the increased supplementation provided an economical benefit (Morris et al., 2006; Rolfe, 2011; Griffin et al., 2012; Gillespie-Lewis et al., 2015; Gillespie-Lewis et al, 2016). Morris et al. (2006) conducted an economic analysis of steers provided increasing levels of DGS on summer range before finishing on a common ration. As steers were supplemented increasing levels of DGS (0.26 to 1.03% BW), final BW increased providing increased sellable weight. Morris determined that a producer planning to sell calves after the summer grazing would see the greatest economic return by supplementing the greatest level of DGS (1.03% BW), while a producer who retains ownership through the feedyard would supplement the middle level of DGS (0.51% BW) during the summer. Although the steers supplemented the greatest level of DGS during the summer had the greatest final BW, the increased cost of DGS did not return increase in BW that was economically beneficial compared to the middle level of supplementation. Rolfe (2011) discussed similar results of summer-supplemented steers providing decreased DOF in the feedlot and increased sellable weight, which resulted in increased profit over non-supplemented calves. While

Morris and Rolfe focused only on a summer-supplemented system, the study discussed previously by Griffin et al. (2012) evaluated calf-fed versus long-yearlings. Long-yearlings were placed in the feedlot at increased BW, thus reducing DOF needed to finish. As DOF are reduced, total feed consumed and yardage paid decreases. The increase of 38 kg final BW and 24 kg HCW for the long-yearlings compared to the calf-feds attributed to increases in revenue generated. While there was no difference in quality grade between the systems, the long-yearlings were more profitable due to the increase in sellable weight and decrease in total feed cost and yardage.

Gillespie-Lewis et al. (2015) conducted a meta-analysis of six backgrounding studies to determine profitability of system utilized. In the studies, calves were supplemented either a high or low level during winter corn residue grazing followed by summer grazing with no supplement and finished on a common diet. Similar to all other studies discussed previously, Gillespie-Lewis reported the lower supplemented calves gained more during the summer compared to the high winter supplemented calves; however, the high supplemented calves gained 0.35 kg/d more in the feedyard. The increase in finishing ADG equated to an increase in final BW and increased revenue generated. Gillespie-Lewis et al. (2015) also conducted a sensitivity analysis of the impact corn price has on profitability when utilizing a long-yearling backgrounding system. Corn prices of $3.00, $ 5.00, and $7.00/25.4 kg ($/bushel) were evaluated utilizing the animal performance data. The greatest profit was returned for the $3.00/25.4 kg corn, while the lowest profit returned was for the $7.00/25.4 kg corn. However, when comparing all three pricing scenarios, the high winter supplemented calves had an average increased profit of $88.50 per calf over the low supplemented calves. This meta-analysis suggests that supplementing increased DGS amounts during the winter in a three-phase system is more profitable compared with lower levels of supplement.

Although the performance data were previously discussed for the two-year study by Gillespie-Lewis et al. (2016), an economic analysis was also conducted utilizing the performance data within each backgrounding system. Because there was increased input cost of supplement for the high winter supplemented heifers, total overall cost of the system tended to be increased by $32.52 per heifer for year 1 while not different in year 2. However, similar to other studies discussed, revenue generated for the high winter supplemented heifers was $98.61 and $69.59 greater than the low amount of supplementation due to the additional 24 and 15 kg of HCW gained (Year 1 and 2, respectively). As with other reported data, the increase in revenue for the high supplemented heifers equated to $66.10 and $37.71 greater profit per heifer (Year 1 and 2, respectively) compared to the lower amount of DGS supplemented heifers.

Based on the economic analyses, the authors conclude that supplementing in a backgrounding system is profitable. Nevertheless, which level to supplement is dependent on whether ownership of the calves is retained through the feedlot. If calves are retained throughout a three-phase backgrounding system, supplementing at a higher level in the winter while not supplementing during the summer, increases sellable weight and ultimately profitability. Data reporting increases in HCW through increased supplementation have been variable which creates uncertainty in generating sufficient revenue to overcome the additional supplement cost. Thus, the optimal amount of DGS supplement to provide calves during the winter backgrounding phase to increase growth and performance while maintaining profitability must be defined.

Serial Slaughter of Beef Cattle

Growth rate of beef cattle

Growth can be defined as the accretion of protein, fat, and bone over the lifetime of an animal (Owens et al., 1995). Generally speaking, growth of an animal is thought of as a measured value such as gain over a period of time and can be expressed as BW gain or ADG. Animal growth is largely dictated by energy intake (Owens et al., 1995) but is also influenced by genetics, body composition, and maturity (Ferrell and Oltjen, 2008). By further understanding the factors which influence rate and composition of cattle growth, improved management practices and marketing strategies can be implemented.

Garrett et al. (1959) compared energy requirements of sheep and cattle for maintenance and gain. Feed energy was expressed as TDN, DE, and ME to determine the effect on net energy requirements and subsequent performance. Garrett et al. (1959) concluded that TDN, DE, and ME were viable parameters for estimating energy requirements for beef cattle. Lofgreen and Garrett (1968) further developed the concept and equations of net energy requirements of beef cattle to include both growing and finishing calves in which the equations were integrated into the NRC Nutrient Requirements of Beef Cattle over the years (1976, 1984, 1996, 2000, and 2016). Although feed energy intake accounts for a large portion of animal growth, it alone does not account for variation. Other factors such as genetics also have an impact.

Old and Garrett (1987) evaluated breed effect on beef cattle growth utilizing Hereford and Charolais calves fed at low, medium, and *ad libitum* energy intakes. Old and Garrett (1987) reported that breed had an impact on energy utilization and partitioning. Feed energy was utilized more efficiently by Hereford steers than the Charolais steers and the steers fed at *ad libitum* intake utilized feed energy less efficiently than those fed at decreased intakes. It was also determined that breed affected protein accretion and fat deposition where Charolais steers developed increased protein accretion compared to Hereford steers, while fat deposition was increased later in the feeding period for the Hereford steers compared to the Charolais. Old and Garrett (1987) concluded that protein accretion versus fat deposition was increased for steers fed lower intakes, regardless of breed type, compared to those fed *ad libitum*. Drouillard et al. (1991) reported similar findings after evaluating the effect of protein and energy restriction on compensatory growth.

Protein accretion and fat deposition

Owens et al. (1995) reviewed factors that affect growth and maturity of beef cattle over their lifetime, mainly during feeding. Owens described the beef industry as economically driven by carcass weights and quality, which can be influenced by management practices and animal growth. Those management implementations affect the economics because carcass weight is largely determined by protein accretion and quality is determined by fat deposition. Thus, understanding growth as a proportion of protein accretion and fat deposition is critical to marketing strategies of beef cattle. Owens et al. (1995) stated that as cattle reach mature body size, protein accretion decreases to zero although fat deposition can continue to increase. As described earlier, fat deposition can be altered through nutrient restriction (Old and Garrett, 1987; Drouillard et al., 1991), but Owens states that fat deposition appears to reach a plateau when given *ad libitum* access to a high energy diet at 550 g/d. However, protein accretion continues as a proportion of empty body weight but can be altered by influences which affect mature size such as backgrounding. Although deposition of fat is 1.7 times more energetically advantageous, protein deposition as a portion of mass is four times more efficient because muscle contains 75% water (Owens et al., 1995).

Pethick et al. (2004) evaluated the growth curve of beef cattle to determine its influence on marbling (intramuscular fat). Pethick et al. (2004) concluded that three phases of growth existed for beef cattle in which marbling does not increase (growth up to 200 kg HCW), a period of linear increases in marbling (200 to 450 kg HCW), and growth to mature body size where marbling ceases to increase (~ 500 kg HCW). Pethick et al. (2004) described nutrient restriction in steers, in this case backgrounding or growing calves, had an impact on marbling deposition later in the growth curve of the animal. Pethick et al. (2004) also confirmed that the greatest impact on marbling is achieved through increases in net energy of the feed provided. May et al. (1992) and Van Koevering et al. (1995) determined that increasing DOF increased fat deposition both subcutaneously and intramuscularly (marbling), while also increasing size of LM. Although quality grade was marginally affected by increasing DOF for finishing steers, tenderness and palatability was improved (May et al., 1992; Van Koevering et al., 1995).

These data suggest that alterations in feed energy intake, physiological maturity of the animal, or DOF at the end of finishing period have an impact on protein accretion and fat deposition. It can be beneficial to alter management strategies, which affect these depos, ultimately to impact carcass weight and quality. However, proper tools are needed to evaluate growth in the form of protein and fat deposition, which are not invasive to the animal and can be utilized accurately.

Carcass ultrasound of beef cattle

Many strategies have been implemented in an attempt to measure the growth of cattle including serial slaughter, regression models, and adaptation of ultrasound technology. The use of ultrasound procedures is preferred over other strategies because it is non-invasive, i.e. does not require slaughter of the animal as with serial slaughter. Generally speaking, the common carcass ultrasound measures collected for beef cattle are 12^{th} rib fat thickness (**BF**), percentage intramuscular fat (**PIMF**), and longissimus muscle area (**LMA**). Many researchers have evaluated the efficiency of carcass ultrasound techniques and associated software to increase the accuracy of prediction models (Brethour, 1992; Wilson, 1992; Hassen et al., 1999; Wilson et al., 1999; Brethour, 2000; Bruns et al., 2004).

In the study by Brethour (1992), BF was measured via ultrasound techniques to determine the repeatability and accuracy compared with carcass measures collected. Brethour (1992) determined the greater the fat content, the greater the error when utilizing ultrasound, and fat thickness when measured via ultrasound, was 8% lower than that of carcass measurement. However, Brethour (1992) went on to suggest that ultrasound measures of BF might be more accurate than carcass measurements due to changes in BF after harvest and cooling. Brethour (1992) reported the simple correlation to be r = 0.975 for BF ultrasound and concluded that ultrasound techniques to measure BF were adequate to replace serial harvest methods to determine BF growth. Smith et al. (1992) conducted a similar study to determine the accuracy of BF and LMA ultrasound measurements to carcass measurements. Correlation coefficients were determined to be 0.81 and 0.82 for BF, and 0.43 and 0.63 for LMA (year 1 and year 2, respectively). This coefficient for BF is less than that described by Bethour (1992), but Smith et al. (1992) concluded the ultrasound prediction for BF to be accurate and predictions for LMA utilizing ultrasound are inconsistent due to animal to animal variation.

More recent work has been conducted by Brethour (2000), Crews and Kemp (2001), Greiner et al. (2003), and Bruns et al. (2004) utilizing advanced technology and techniques of ultrasound to determine prediction of carcass merit. Brethour (2000) evaluated serial ultrasound measurements to determine if accuracy could be improved in order to develop prediction models. Brethour (2000) reported that accuracy of marbling prediction via PIMF was increased as days between ultrasound measurement and harvest date decreased. It was concluded by Brethour (2000) that BF and PIMF contained minor coefficient of determination relationships ($r^2 = 0.07$ and 0.16, respectively) for prediction of quality grade, but both ultrasound measurements could be utilized accurately to predict carcass merit. Crews and Kemp (2001) evaluated the use of ultrasound to predict merit of breeding animals. It was determined that ultrasound LMA and BF measurements were highly correlated with carcass measurements, but different prediction models must be used between heifers and bulls. Similar to Brethour (2000), Crews and Kemp (2001) determined small negative correlations between BF and PIMF measures concluding that ultrasound BF measures could not be used to predict marbling score for growing animals. A similar study was conducted by Greiner et al. (2003) to determine the relationship between ultrasound and carcass measurements of BF and LMA. Greiner reported increased variability for ultrasound LMA compared to carcass measurements, while ultrasound BF accurately predicted carcass BF. In a study by Bruns et al. (2004), PIMF measurements were utilized to predict relationships between body weight and composition of steers. Bruns et al. (2004) reported that sorting steers into marbling groups based on PIMF measurements had no effect on BF, LMA, YG, or carcass marbling score. Bruns et al. (2004) concluded that marbling develops throughout development of the calf rather than late in feeding period; thus, PIMF measures over the feeding period could be utilized to predict marbling score at finish.

Although correlations are not precise between PIMF and marbling score, the data suggest that ultrasound technology has improved in prediction accuracy over the years. If proper training and techniques are utilized, ultrasound measurements can be collected to accurately predict growth models for BF, PIMF, and LMA for beef cattle. These measurements can aid producers in predicting optimal marketing time based on protein and fat deposition.

Live, carcass, and grid based marketing

Cattle feeders have several methods to market cattle which include on a live weight basis, a carcass weight basis, or on a grid basis. Calves sold on a live weight basis are paid on the amount of live weight upon leaving the feedlot minus shrink, while calves sold on a carcass weight basis are paid based on the HCW of the animal after harvest. The final method of marketing, grid basis, is the most complex because each individual calf is valued based on merit of their carcass including HCW, quality grade, and yield grade. Each market strategy has its advantages and disadvantages, which can be dependent on breed type, environmental conditions, commodity prices, and market conditions.

In recent years, marketing strategies for beef producers have shifted towards increasing the number of cattle sold on a carcass or grid basis (Walter and Hale, 2011; Streeter et al., 2012). The shift in marketing strategy has been attributed to improvements in quality of cattle fed (which leads producers to capture value) or recent decreases in calf supply, which increases feeder price, thus producers attempt to recover increased input costs. Cattle marketed on a live basis are generally evaluated by live performance (BW gain) and cost of gain associated with performance. Cattle are marketed on a live basis when the incremental cost of additional weight equals the revenue generated (Streeter et al., 2012; Wilken et al., 2015). While this method can be beneficial to producers who feed cattle which do not have the genetic potential for increased quality grade, there could be uncaptured revenue in HCW due to carcass transfer. Additionally, live performance is not always indicative of carcass performance. If cattle are to be sold on a carcass or a grid basis rather than live, consideration must be given to carcass transfer at the end of the finishing period, which can be as great as 88.6% (Streeter et al., 2012). Consequently, several researchers have evaluated the impact of carcass and grid based marketing strategies utilizing economic analyses (Pyatt et al., 2005; Streeter et al., 2012; Tatum et al., 2012; Wilken et al., 2015). However, results of these studies have been highly variable due to market conditions utilized within analyses.

In a report by Fuez (2002), simulated economic analyses were conducted to determine if feeding increased DOF improved profitability for calves marketed on a grid basis. Fuez concluded that increasing DOF had the potential to increase premiums received for quality grade on a grid. However, as DOF increased, the discounts received for YG and overweight carcasses increased but could be overcome through additional HCW revenue and quality grade premiums. Similar marketing strategies were described by Walter and Hale (2011) who evaluated close-out data. Walter and Hale (2011) concluded increases in HCW revenue and quality grade premiums had the potential to overcome YG 4 and 5 and overweight discounts with respect to market conditions. Carcass based sales increase sellable weight while increasing market window, and the steers with greatest profitability had increased HCW, percent Choice and Prime grade, and greatest number of YG 4 and 5 carcasses (Walter and Hale, 2011).

The study by Pyatt et al. (2005) applied 5-yr average prices to steers marketed on a grid basis to determine which performance and carcass traits had the greatest impact on profitability. Pyatt et al. (2005) determined that HCW, marbling score, and YG accounted for 80% of the variation in carcass value (51, 10, and 8%, respectively), but profitability was highly correlated to DMI, ADG, G:F, HCW, and marbling score. Steer HCW, marbling score, YG, and DMI accounted for almost 78% of profit (21, 18, 12, and 3%, respectively). The data describe the impact of live animal performance on profitability due to feed costs associated with intake and cost of gain. However, Pyatt et al. (2005) went on to conclude HCW was the greatest determinate for carcass value while BW and carcass quality was most critical for determining profit. In an economic analysis of 67,570 lots of commercial cattle evaluated by Tatum et al. (2012), conflicting results to Pyatt et al. (2005) were described. Tatum et al. (2012) reported that carcass-based G:F was the most critical value determining net return and the most important traits determining value of carcass gain were carcass ADG and DOF. Contrary to the conclusion of Pyatt et al. (2005), Tatum et al. (2012) concluded that carcass weight had the greatest influence on profitability over quality grade performance when utilizing a grid marketing strategy. The results of Tatum would coincide with reports by Fuez (2002) and Walter and Hale (2011) who stated HCW revenue has the greatest influence on profitability.

The data reported by Tatum et al. (2012) describes a factor that has increasing influence on profitability when marketing on a carcass or grid basis, days on feed. Streeter et al. (2012) evaluated large pen studies with steers and heifers fed increasing DOF to determine the impact on marketability on both a live- and carcass-basis. As DOF were increased, live ADG decreased at an increasing rate compared to carcass ADG due to carcass transfer (transfer of live weight gain to carcass weight) of 88.6% and 87.3% for steers, and 86.6% and 65.8% for heifers (first and second harvest groups, respectively). Streeter et al. (2012) determined steer carcass ADG to be 0.95 kg/d equating to 17 and 20 kg increases in HCW as DOF increased by 21 d increments. Streeter et al. (2012) concluded that optimal DOF was dictated by marketing strategy utilized; cost of gain was not the determining factor when marketing on a carcass or grid basis. While the optimal DOF for steers is determined mainly by overweight carcass discounts, the optimal DOF for heifers is generally dictated by YG discounts due to physiological maturity i.e. fat deposition differences. Although the data presented by Streeter et al. (2012) offers insight into the impact of increasing DOF for steers and heifers, market conditions were held constant for analysis. Consequently, the effect of market conditions on optimal DOF has not been determined.

Wilken et al. (2015) utilized seven trials conducted at the University of Nebraska-Lincoln to develop regression models, which would predict the relationship between HCW gain and corn price on profitability. In this study, steers were marketed at 75, 100 (1.2 cm BF), and 125% DOF on both a live and carcass basis utilizing economic variations in corn price which included \$3.50, \$5.50, and \$7.50/25.4 kg (\$/bushel). Wilken et al. (2015) reported BW gain to increase quadratically at a decreasing rate while HCW increased quadratically at an increasing rate, and carcass transfer increased linearly up to 90%. The reported carcass transfer by Wilken is similar to that reported by Streeter et al. (2012) of 88.6% for steers fed 21 additional DOF. Similar to data reported previously, Wilken also reported linear decreases in live G:F and quadratic decreases in HCW-based G:F. When applying the economic scenarios to the performance data, Wilken determined similar net returns for steers at 100% DOF regardless of marketing on a live or carcass basis. However, the greatest net returns were realized for steers fed increasing DOF and marketed on a carcass basis. These data correspond to the data previously described by Fuez (2002), Walter and Hale (2011), and Streeter et al. (2012) when evaluating marketing strategies and associated profitability.

However, these studies have not elucidated the correlations between DOF and market conditions when a grid basis is applied. While the Wilken et al. (2015) data set evaluated live versus carcass-based marketing under varying economic scenarios for corn price, individual carcass data were not utilized to determine the effect of market prices on profitability when a grid basis is applied to cattle fed increasing DOF. By further understanding the performance and growth curve of cattle on a carcass basis, producers have the ability to determine optimal marketing time when selling on a grid basis.

Summary

Variables such as land resources, environmental conditions, market prices, and consumer demand will continue to have a profound impact on the beef industry. As these variables or conditions change, management strategies and feeding practices must continue to evolve to remain competitive. One technique widely utilized within the beef industry is use of by-products, such as crude glycerin and DGS, in beef cattle diets to provide additional protein and/or energy. Another management technique is the use of extensive long-yearling beef systems to align production cycles with resources available. Lastly, a more recent strategy utilized by beef producers is extending the days on feed of cattle fed for slaughter to increase weight and capture additional revenue. Each management technique and strategy presents its own set of challenges, but if overcome, can provide an opportunity for increased return on investment.

Research over the years has demonstrated that crude glycerin can be utilized in beef cattle production systems. In the case of crude glycerin, it can be incorporated up to 15% (most species) as an energy source within diets due to its gluconeogenic properties. In many cases, especially in beef cattle diets, there is a potential to replace a percentage of corn grain with crude glycerin and realize similar animal performance, which could potentially decrease the quantity of corn needed. Results for crude glycerin inclusion in beef cattle diets have been conflicting, but similar results for performance have been noted as long as glycerin inclusion remained ≤ 15%. Due to rumen fermentation characteristics of glycerin, it appears that crude glycerin is most beneficial when used in diets containing lower concentrate levels such as growing diets. Glycerin inclusion can increase propionate production while decreasing acetate production, which leads to increased ruminal and animal efficiency (decreased loss of carbon to CO_2 and methane). However, its impact on fiber digestion in beef cattle has yet to be identified.

The use of backgrounding systems to maximize cattle production utilizing resources is not a new concept. However, the addition of byproducts and their use within backgrounding systems to meet animal deficiencies has been a topic of discussion in recent years. Crop residues, improved grasses, native range, and high-forage growing diets may not provide adequate protein, particularly bypass protein, or energy for proper growth and efficient production. Because DGS contain 30% CP, 63% of which in the form of RUP (Castillo-Lopez et al., 2013), DGS becomes a valuable supplemental resource to meet protein deficiencies which are common in high-forage situations. Supplementing DGS supplies adequate CP and RUP while reducing the calf's demand on the forage, allowing for forage savings or an increase in stocking rate. Supplementing at increased rates of DGS above protein requirements appears to provide energy to the animal and subsequent increases in ADG and BW. By increasing the BW of cattle at feedlot entry, the DOF can be decreased, thus decreasing total feedlot costs for feed and yardage, which is consistently the most costly portion (excluding calf purchase cost) of the production cycle. There is no effect on feedlot performance for calves which are grown in a three-phase backgrounding system because of a compensatory gain response during the second phase. However, the data have been variable whether HCW is increased by supplementing increased amounts of DGS during the winter with no supplementation during the summer in a three-phase system. If revenue is increased by increasing sellable weight, there is potential to offset the input costs of supplementation during the winter. Therefore, the optimal amount of DGS supplementation must be defined to maximize animal performance, growth, and revenue while maintaining profitability.

Understanding the growth curve of beef cattle is imperative to making sound management and marketing decisions. Growth of an animal is largely determined by energy intake, genetics, body composition, and maturity. While energy restriction can increase energy utilization once adequate nutrition is available, genetics can alter the proportion of protein to fat mass which is deposited on the carcass. Protein and fat as a proportion of growth are deposited at different rates and timepoints along the growth curve as animals reach physiological maturity. While Owens et al. (1995) stated that the industry was driven by weight and quality of carcasses, other researchers confirmed this by conducting economic analyses on cattle marketed on carcass and grid basis. These data suggest that increases in HCW revenue can overcome YG and overweight carcass discounts under specific market conditions. In an attempt to increase HCW revenue, producers have increased DOF which can further increase discounts associated with YG and overweights, but premiums for quality grade. Although the Wilken et al. (2015) data evaluated the effect of DOF and HCW gain on profitability while varying market conditions were applied, a grid based marketing strategy was not utilized. There is not sufficient data describing the impact of market conditions on increasing DOF when a grid based strategy is used to target optimal marketing timepoint. Thus, further research is needed discussing the impact of DOF on carcass merit (HCW, quality grade, and YG) when evaluated on a grid basis under variable market conditions to determine when profitability is minimized and maximized.

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CHAPTER II

Effect of crude glycerin concentration on forage digestion parameters in beef calves.[1]

R. G. Bondurant[*], J. L. Gramkow*, M. L. Jolly-Breithaupt*, A. R. McCain*, S. C. Fernando*, and J. C. MacDonald, PAS*.

[*]Department of Animal Science, University of Nebraska, Lincoln, NE 68583-0908

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ABSTRACT

An experiment was conducted to determine the effects of crude glycerin (**GLY**) on total tract digestibility, rate and extent of fiber digestibility and rumen fermentation parameters. Seven ruminally and duodenally cannulated crossbred steers were arranged in a row × column transformation consisting of four periods and four treatments. Crude glycerin replaced soybean hulls (**SH**) at 0%, 4%, 8%, or 12% of diet DM. Basal diets consisted (DM basis) of 50% wheat straw (**WS**), SH, 4% supplement, and soybean meal. Fecal, rumen and duodenal samples were collected at -1, 2, 5, and 8 h relative to feeding. *In situ* bags containing ground WS or SH were incubated in the rumen for 0, 6, 12, 16, 24, 48, and 96 h to determine NDF digestion rates. Both DM and OM intake decreased quadratically ($P = 0.04$) as GLY increased in the diet, with lowest DMI and OM intake at 4% GLY inclusion. As GLY inclusion increased from 0 to 12% of diet DM, NDF intake linearly decreased from 6.01 to 5.26 kg ($P < 0.01$). Glycerin inclusion had no effect on total tract OM digestibility ($P \geq 0.73$). Total tract NDF digestibility decreased linearly ($P = 0.02$) from 62.6% to 53.8% as GLY increased in the diet. However, the inclusion of GLY had no effect on *in situ* rate of NDF digestibility ($P \geq 0.27$ for linear or quadratic contrast) for WS or SH. Molar acetate proportion decreased linearly ($P < 0.01$), propionate concentration increased linearly ($P < 0.01$), and molar butyrate proportions quadratically increased ($P < 0.01$) as GLY increased and time post-feeding progressed. While rumen microbial populations of *Fibrobacter succinogenes, Butyrivibrio fibrosolvens*, and *Megasphaera elsdenii* did not change ($P > 0.27$ for linear or quadratic contrast), populations of *Selenomonas ruminantium* and *Anaerovirbrio lipolytica* linearly

increased ($P \leq 0.02$) as GLY inclusion increased in treatment diets. The inclusion of GLY in forage-based diets did not impact NDF digestibility and decreased acetate to propionate ratio ($P < 0.01$) which could result in improved G:F.

Key Words: Cattle, digestion, fiber, glycerin, volatile fatty acid

INTRODUCTION

Byproducts have been utilized by the beef industry for decades to decrease production costs and in some cases, improve animal performance. With the expansion of the renewable fuels industry such as biodiesel, feedstuffs like crude glycerin (**GLY**) have become available to livestock producers. During the production of biodiesel, triglycerides are cleaved to form methyl esters of fatty acids and GLY. Crude glycerin has been studied in many livestock species including finishing ruminants (Parsons et al., 2009; Hales et al., 2015), growing beef cattle (Hales et al., 2013a and Hales et al. 2013b), dairy cattle (Fisher et al., 1971 and Sauer et al., 1973), and in swine (Lammers et al. 2008 and Shields et al., 2011). However, the majority of data reported for beef cattle are evaluating GLY in high-concentrate finishing diets. Hales et al. (2013a) reported quadratic increases in growing calf ending BW and ADG as GLY replaced corn up to 7.5% and decreased to 10% inclusion of GLY. When GLY replaced 7.5% alfalfa hay in growing diets, ending BW and ADG were greater compared with a negative control and a diet with 7.5% GLY replacing steam-flaked corn (Hales et al., 2013a). Hales et al. (2013b) replaced roughage at 0, 2.5, 5.0, and 10% diet DM with GLY in growing diets and reported an improvement in G:F as GLY inclusion increased. Hales et al. (2013b) associated the improvement in

G:F with an increase in ruminal propionate and subsequent decrease in acetate to propionate ratio as dietary GLY inclusion increased. These data suggest that GLY can be incorporated into growing diets replacing corn or forage to yield increases in performance. However, data evaluating the effects of GLY inclusion on fiber digestion in a forage-based growing diets are limited. Thus, the objective of this experiment was to evaluate increasing inclusion of GLY in a forage-based diet to determine its effect on total tract digestibility, rate and extent of fiber digestibility, rumen fermentation parameters, and microbial species abundance.

MATERIALS AND METHODS

All procedures used for this experiment involving animal care were approved by the University of Nebraka-Lincoln Institutional Animal Care and Use Committee (IACUC 902).

Seven ruminally and duodenally cannulated crossbred steer calves were assigned randomly to one of four treatments in a row × column transformation including four periods. For each period, steers were allowed 9 days for adaptation and 5 d for collection. The four dietary treatments (Table 1) consisted of 0%, 4%, 8%, or 12% of diet DM GLY (REG Ralston LLC., Ralston, IA) inclusion. The feed label from supplier reported the GLY to contain 79.5% glycerin, 0.03% methanol, 6.5% ash, 0.12% total fatty acids, and 11.9% moisture (As-is basis). Basal diets consisted of 50% ground wheat straw (**WS**), ground soybean hulls (**SH**; ADM, Fremont, NE), 4% supplement, and added soybean meal to maintain a consistent CP concentration throughout treatment diets. Dietary WS was ground to pass through a 3-mm screen. Dietary GLY replaced SH in treatment diets.

Water was added to treatment diets in amounts to equal 60% diet DM in an attempt to aid in palatability. Salt was added to 0, 4, and 8% GLY diets in amounts to equal the Na content of the 12% GLY diet 0.40% diet DM) in an attempt to minimize variances in intake caused by Na content. All diets contained 200 mg monensin (Rumensin 90; Elanco Animal Health, Greenfield, IN) per steer daily. Steers were not implanted.

Diets were mixed twice per wk in a stationary ribbon mixer (model S-5 Mixer; H. C. Davis Inc., Bonner Springs, KS). Wet feed ingredients and treatment diets were stored at 4°C in a walk-in cooler to maintain freshness and prevent mold growth. Steers were fed once daily at 0800 h and given ad libitum access to feed and water. Feed refusals were weighed and removed daily. During the collection period, feed refusals for individual steers were sampled daily (10% of daily refusal weight), dried at 60°C (model LBB2-21-1; Despatch Industries, Minneapolis, MN) for 48 h (AAOC, 1965; method 935.29) to determine DM content, composited by period, and frozen (-20ºC) for analyses. Once per wk, a sample (100 g) of each treatment diet was dried in a 60ºC oven for 48 h to determine DM content to assure proper diet DM formulation.

Steers were ruminally dosed with 5 g of TiO_2 twice daily (10 g/d) at 0800 and 1600 hours from d 3 to 13 to estimate fecal output. During the 5 d collection period, fecal grab samples, rumen and duodenal fluid samples were collected 1 h before feeding and at 2, 5, and 8 h post feeding. Two 250-mL rumen fluid samples were collected via suction strainer technique described by Raun and Burroughs (1962). Two 250-mL samples of duodenal fluid were collected from duodenal cannula. For each steer on d 14, whole rumen contents (2 kg) were collected 1 h before feeding and mixed with 2 L of formalin/saline solution (3.7% formaldehyde and 0.9% NaCl) for bacterial cell isolation. After each collection, all samples were stored in -20°C for later compositing and analysis.

Fecal samples were composited by d on an equal wet weight basis, lyophilized (Virtis Freezemobile 25ES, Life Scientific, Inc., St. Louis, MO), and ground through a 1-mm screen using a Wiley mill (No. 4, Thomas Scientific, Swedesboro, NJ). The lyophilized and ground daily composites were composited on a dry weight basis by steer within collection period. As described by Myers et al. (2004), fecal samples were analyzed for titanium dioxide concentration which was used to calculate fecal DM output through use of the equation (Cochran and Galyean, 1994): marker dose (g/d) / concentration of marker in feces (g/g of DM). Fecal samples were analyzed for NDF with sodium sulfite (Van Soest et al., 1991), and were ashed in a muffle furnace for 6 h at 600°C (AOAC, 1999; method 4.1.10) to determine percent OM.

Rumen fluid samples were prepared according to Erwin et al. (1961) and were analyzed for VFA concentration using a Trace 1300 (Thermo Fisher Scientific, Inc., Omaha, NE) gas chromatograph. Chromatograph and column settings and standards were set according to the methods described by Gramkow et al. (2016). Whole rumen contents were composited across steers within dietary treatment, blended, and centrifuged to isolate bacterial cells (Leupp et al., 2009). Whole rumen contents were blended (Model 5011, Dynamics Corporation of America, New Hartford, CT) on high speed for 1 min and strained through 4 layers of cheesecloth. Strained rumen fluid was placed in a centrifuge bottle and centrifuged at 500 × g for 20 min at 4°C to remove feed particles and protozoa. The supernatant was removed and centrifuged again at 500 × g for 20 min at 4°C. After bacteria were separated from free supernatant by centrifuging 30,000 × g for 20 min at 4°C, bacterial samples were frozen at -4°C and lyophilized.

Duodenal contents, bacterial isolates, and fecal samples were analyzed for purine concentration to determine microbial flow using a modified Zinn and Owens (1986) procedure with a more dilute $HClO_4$ to hydrolyze material containing purines (Crawford et al., 2008). Purine concentration was determined on a spectrophotometer (SprectraMax 250, Molecular Devices, Sunnyvale, CA) at 260 nm. True ruminal digestibility was calculated as the difference between the amount of nutrient ingested and the amount present at the duodenal cannula after correcting for microbial nutrient contributions.

Individual feed ingredients were dried in a 60°C forced air oven weekly to ensure accurate DM when mixing dietary treatments (Buckner et al., 2011). Samples of individual ingredients were collected before mixing diets, composited by period, lyophilized (Virtis Freezemobile 25ES, Life Scientific, Inc., St. Louis, MO), and ground through a 1-mm screen using a Wiley mill. Fecal samples and feed samples not used for diet composition were analyzed for OM, CP, and NDF to calculate nutrient composition of dietary treatments (Table 1). Crude protein was determined using a combustion chamber (TruSpec N Determinator, Leco Corporation, St. Joseph, MI; AOAC, 1999; method 990.03). Neutral detergent fiber analysis was conducted using the procedure described by Van Soest et al. (1991). Nutrient composition of dietary treatments and feces were used to calculate total tract digestibility of OM and NDF. Total tract digestibility was calculated using the following equation (Cochran and Galyean, 1994);

[(Nutrient fed, kg – Nutrient refused, kg – Nutrient in feces, kg) x 100] / (Nutrient fed, kg – Nutrient refused, kg).

Representative samples of WS and SH were ground through a 2-mm screen in a Wiley mill for *in situ* utilization. For each fiber source, 1.25 g of sample was weighed into a pre-weighed, labeled polyester bag (5 × 10 cm; Ankom, Fairport, NY) and double sealed with an Ankom heat sealer (Ankom Technology Corp., Macedon, NY). On d 10 of each period, triplicate *in situ* sample bags containing WS or SH were incubated in the rumen for 0, 6, 12, 16, 24, 48, and 96 h to determine NDF digestion rates. Replicate *in situ* bags were incubated in all steers for each period. All sample bags were contained within a polyester laundry bag (36 cm × 42 cm) to ensure similar sample location within the rumen and aid in removal. To ensure rinsing conditions were identical within run, sample bags were placed in the rumen at the appropriate time interval so that all bags were removed together to be rinsed. Upon removal from the rumen, bags were washed in a washing machine using a 1-min agitation and 2-min spin cycle which was repeated 5 times (Haugen et al., 2006) and then rinsed with distilled water. After rinsing, samples were refluxed in NDF solution in a Fiber Analyzer (Ankom Technology Corp., Macedon, NY). Samples were dried in a forced air oven at 60° C (model LBB2-21-1; Despatch Industries, Minneapolis, MN) for 24 h and weighed to determine remaining NDF in sample bags.

Samples were collected from ruminal and duodenal cannulas 8 h post-feeding on the last day of the 14-d period. Samples were immediately frozen and remained frozen until the completion of the trial. Utilizing techniques and primers described by Fernando et al. (2010), total DNA was extracted from the rumen and duodenal samples and the microbial species abundance was quantified using quantitative real-time PCR with species-specific primers. Real-time assays were performed using the SYBR Green reporter assay and the relative fold change in the rumen and duodenum were calculated using the ΔΔ CT method relative to the control for each species (Fernando et al., 2010). The 16S rRNA gene was used to normalize the data before fold change was calculated.

Utilizing techniques described by Tedeschi et al. (2009), digestion rates for WS and SH were fitted using PROC NLIN in SAS and the Gauss-Newton method to obtain the fractional rate of fermentation per hour. *In situ* data for rate of NDF digestibility and relative microbial abundance data were analyzed using the MIXED procedure of SAS (SAS Institute, Inc., Cary, N.C.). Digestibility and *in situ* extent of NDF digestion data were analyzed using the GLIMMIX procedure of SAS (SAS Institute, Inc.). For all statistical analyses, steer within period was the experimental unit while the model included fixed effects of dietary treatment and period, and steer was included as a random effect. Preplanned orthogonal contrasts were used to test linear and quadratic effects of GLY inclusion. Ruminal VFA data were analyzed using the MIXED procedure of SAS (SAS Institute, Inc.) with time within d as the repeated measure. Six covariate structures were tested (unstructured, variance components, Cholesky, autoregressive, Toeplitz, and compound symmetry), and the structure which resulted in the lowest Bayesian information criterion was determined the best fit. The autoregressive covariance structure [AR (1)] provided the best fit for VFA data. Treatment effects were considered a tendency at $P < 0.10$ and significant at $P < 0.05$.

Results and Discussion

As GLY increased in the diet, DM and OM intakes decreased ($P = 0.04$), with lowest intakes occurring at 4% GLY inclusion while 0, 8, and 12% GLY were not different (Table 2). As GLY inclusion increased from 0 to 4, 8, and 12% diet DM, NDF intake linearly decreased ($P < 0.01$) (6.01, 5.46, 5.37, and 5.26 kg, respectively) because GLY displaced SH, thereby reducing the dietary NDF concentration, and NDF intake decreased. These results are similar to Hales et al. (2015) where they noted a linear decrease ($P < 0.01$) in OM and NDF intakes as GLY was increased in finishing diets replacing dry-rolled corn at 0%, 5%, 10%, and 15% diet DM. However, when GLY replaced roughage at 0%, 2.5%, 5%, and 10% diet DM in growing diets, DM and OM intakes were not affected while NDF intake decreased linearly (Hales et al., 2013b). When evaluating the effect of GLY on NDF parameters, the dietary NDF content and digestibility must be considered if GLY is replacing a fiber source in the diet such as the current study or Hales et al. (2013b) where roughage was being replaced.

Increasing dietary GLY from 0 to 12% dietary DM had no effect on apparent OM, true OM, or NDF ruminal digestibility ($P \geq 0.15$). However, Hales et al. (2013b) noted a linear increase in apparent OM ruminal digestibility and a quadratic increase in true OM ruminal digestibility while ruminal NDF digestibility was not affected by GLY inclusion in growing diets. Similar to the current study, in finishing diets replacing dry-rolled corn with GLY at 0%, 5%, 10%, and 15% (diet DM), OM and NDF digestibility were not different among treatments (Hales et al., 2015).

Increasing GLY inclusion tended to linearly decrease (P = 0.10) both total OM and NDF duodenal flow and had no effect on either feed OM or bacterial OM duodenal flow ($P \geq 0.12$). Contrary to the current study, Hales et al. (2013b) reported that bacterial OM duodenal flow increased quadratically and feed OM duodenal flow decreased quadratically while total OM and NDF duodenal flow was not different as GLY increased from 0 to 10% in growing diets.

Glycerin inclusion had no effect on OM or NDF fecal output ($P \geq 0.20$). Contrary to these results, both Hales et al. (2013b) and Hales et al. (2015) observed decreases in OM and NDF fecal excretion as GLY inclusion increased in growing and finishing diets, respectively. As GLY inclusion increased from 0 to 12% dietary DM, total apparent OM digestibility was not different among treatments ($P \geq 0.73$) while total apparent NDF digestibility tended to decrease linearly (P = 0.08) from 62.6 % to 53.8%, respectively. Hales et al. (2013b) described different results with a linear increase in total apparent OM digestibility and no difference in total apparent NDF digestion as GLY inclusion increased from 0 to 10% (diet DM) in growing diets. In the growing diets of Hales et al. (2013b), GLY was replacing a roughage source (alfalfa hay) as compared to SH in the current treatment diets. The inclusion of GLY had no effect on the potentially digestible fraction ($P \geq 0.21$) or the *in situ* rate of NDF digestibility ($P \geq 0.15$) for WS or SH (Table 2). Because the GLY is replacing SH which has greater NDF digestibility than WS, the proportion of digestible dietary NDF decreases as SH are removed from the diet. Thus, the decrease in total tract NDF digestibility may not be a result of changes in fermentation but rather a function of the decrease in a more digestible source of NDF as

GLY displaced SH. These data would suggest that GLY does not affect the extent of fiber digestion for both WS and SH.

There was a treatment x time interaction ($P < 0.01$) for all VFA proportions; therefore the simple effects of time post feeding and treatment are discussed. As GLY inclusion increased, molar acetate proportions (Fig 1) linearly decreased ($P < 0.01$) and were significantly different for all GLY concentrations at 2, 5, and 8 h post feeding ($P \leq 0.01$). At 1 h pre-feeding, 0 and 4% GLY fed steers were not different ($P = 0.28$), while 0 and 8% GLY tended to be different ($P = 0.09$), and all were significantly different from 12% GLY ($P \leq 0.01$). Similar results have been reported by other researchers when GLY replaced forage (Wang et al., 2009; Abo El-Nor et al., 2010; Hales et al., 2013b) and when GLY replaced concentrate (AbuGhazaleh et al., 2011; Ramos and Kerley, 2012; Hales et al., 2015). Because GLY is primarily converted to propionate in the rumen (Parsons et al., 2009 and Hales et al., 2015), molar acetate proportions decrease when GLY inclusion increases.

Similar to the results of Hales et al. (2013b), molar propionate proportions linearly increased ($P < 0.01$) as dietary GLY concentration increased and as time post-feeding progressed from -1 to 8 h (Fig. 2). AbuGhazaleh et al. (2011) reported linear increases in propionate as GLY replaced corn from 0 to 45% inclusion in continuous culture fermenters. Similarly, when GLY inclusion was increased in diets containing 60% corn stover and 40% concentrate, propionate concentrations increased (Wang et al., 2009). Because GLY is composed of a 3-carbon molecule, it can be converted directly to a 3-carbon propionate, reducing energy losses to the animal. Because there were decreases in acetate and increases in propionate, the acetate to propionate ratio quadratically decreased ($P < 0.01$) as GLY concentration increased and time post feeding increased to 2, 5, and 8 h (Fig. 3). At 1 h pre-feeding, acetate to propionate ratio for 0, 4 and 8% GLY were not different ($P \geq 0.14$) while all were significantly greater than 12% GLY ($P \leq 0.01$). Regardless if GLY replaced fiber or corn in treatment diets, results were similar for decreases in acetate to propionate ratio as GLY inclusion increased (Wang et al., 2009; Abo El-Nor et al., 2010; AbuGhazaleh et al., 2011).

Butyrate VFA proportions quadratically increased ($P \leq 0.01$) as GLY concentration increased and time post feeding increased to 2, 5, and 8 h (Fig. 4). Butyrate concentration increased ($P < 0.01$) at 2, 5, and 8 h post feeding for 8 and 12% GLY, while proportions were unchanged for 0 and 4% GLY. At 1 h pre-feeding, ruminal butyrate VFA proportions were not different between 0 and 4% GLY ($P = 0.19$), 4 and 8% GLY ($P = 0.58$), while 8% GLY tended to be different from 0% GLY ($P = 0.06$) and 12% GLY ($P = 0.10$). Similar results were reported by Wang et al. (2009) showing increases in butyrate concentration as GLY was increased in diets containing 60% corn stover. Contrary the results of the current study and Wang et al. (2009), both Avila et al. (2011) and Hales et al. (2013b) described decreases in butyrate concentration at increasing levels of GLY inclusion. While Avila et al. (2011) replaced barley with GLY in treatment diets, Hales et al. (2013b) replaced roughage, which is similar to the current study.

It was hypothesized by Stewart et al. (1997) that GLY is metabolized by *Megasphaera elsdenii*, *Streptococcus bovis*, and *Selenomonas ruminantium* and increases in butyrate concentrations have been correlated to increases in *Megasphaera elsdenii*. However, in the current study, microbial population abundance within the rumen for *Fibrobacter succinogenes*, *Butyrivibrio fibrosolvens,* and *Megasphaera elsdenii* did not change ($P > 0.27$) as GLY inclusion increased in treatment diets (Table 3). Within the rumen, *Selenomonas ruminantium* linearly increased up to 21-fold at 12% GLY inclusion ($P = 0.02$) and *Anaerovirbrio lipolytica* linearly increased up to 16-fold at 8% GLY inclusion ($P < 0.01$). Data presented by AbuGhazaleh et al. (2011) utilizing continuous culture fermenters replacing corn with increasing levels of GLY, described decreases in *Butyrivibrio fibrosolvens* and *Selenomonas ruminantium*. While this contradicts results of the current study, it is important to remember AbuGhazaleh et al. (2011) was replacing corn grain with GLY while the current study replaced a fiber source with GLY. An increase in *Anaerovirbrio lipolytica* is indicative of an increase in propionate production while an increase in *Selenomonas ruminantium* indicates an increase in lactate utilization within the rumen. Because there was no change in the abundance of *Megasphaera elsdenii*, which is a lactate utilizer, coupled with increases in *Anaerovirbrio lipolytica* and *Selenomonas ruminantium,* the data suggest that the primary metabolic pathway utilized by bacteria for removal of lactate is the succinate pathway. In the duodenum, *Selenomonas ruminantium* and *Anaerovirbrio lipolytica* linearly increased up to 4-fold (Table 4; $P < 0.01$) and up to 9-fold ($P < 0.01$) at 12% GLY inclusion, respectively. There was no change in abundance for *Fibrobacter succinogenes* and *Megasphaera elsdenii* populations in the duodenum ($P > 0.86$). In the duodenum, *Butyrivibrio fibrosolvens* increased quadratically up to 21-fold at 12% GLY inclusion ($P < 0.01$).

Contradicting results from previous microbial research and the current study could be due to the nature of the analyses conducted, continuous culture fermenters compared to *in vivo*. An increase in rumen microbial population abundance would be indicative of substrate utilization and growth while increases in duodenal microbial population abundance could possibly indicate decreased substrate utilization and increased flow from the rumen. An insignificant effect on *Fibrobacter succinogenes* suggests that fiber digestion is not affected or may not be negatively affected by an increase in GLY inclusion in high-forage diets.

Implications

Although total tract NDF digestibility decreased as crude glycerin inclusion increased, the decrease in NDF digestibility is a result of treatment design rather than a response to glycerin. When evaluating the decrease in dietary NDF digestibility as crude glycerin replaces soy hulls, coupled with no decrease in *in situ* NDF digestibility, the inclusion of crude glycerin in forage-based diets does not impact NDF digestibility. Additionally, *Fibrobacter succinogenes* microbial populations were unaffected indicating that fiber digestion is not impacted by increased inclusion of glycerin. Incorporating crude glycerin in forage-based diets decreases acetate to propionate ratio by increasing the abundance of propionate producing microbial species such as *Anaerovirbrio lipolytica*. A decrease in acetate to propionate ratio may lead to improved feed efficiency, but further research is needed to determine the effect of glycerin inclusion in high-forage growing diets on calf performance.

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Table 1. Diet (DM basis) fed to growing steers to evaluate the effect of increasing dietary crude glycerin concentrations on rate and extent of fiber digestion in high-forage diets.

	Dietary treatments[1]			
Ingredient, % DM	0	4	8	12
Wheat straw	50	50	50	50
Soybean hulls	38.25	33.51	28.78	24.04
Soybean meal	7.75	8.49	9.22	9.96
Crude glycerin	-	4	8	12
Limestone	0.910	0.958	1.005	1.053
Supplement[2]				
Fine Ground Corn	1.074	1.210	1.348	1.483
Salt	0.817	0.545	0.272	-
Urea	0.773	0.846	0.919	0.992
Dicalcium phosphate	0.247	0.262	0.277	0.293
Tallow	0.100	0.100	0.100	0.100
Beef Trace Minerals[3]	0.050	0.050	0.050	0.050
Vitamins A-D-E[4]	0.015	0.015	0.015	0.015
Rumensin-90[5]	0.014	0.014	0.014	0.014
Analyzed Composition, %				
DM[6]	90.7	90.5	90.2	90.0
OM	90.6	90.7	90.9	91.0
NDF	70.5	68.4	65.4	62.6
CP	18.7	18.7	18.3	17.7
Ca	0.7	0.7	0.7	0.7
P	0.2	0.2	0.2	0.2
Na[7]	0.4	0.4	0.4	0.4

[1] 0 = 0% dietary crude glycerin; 4 = 4% dietary crude glycerin; 8 = 8% dietary crude glycerin; 12 = 12% dietary crude glycerin

[2] Supplement formulated to be fed at 4% of dietary DM.

[3] Premix contained 10% Mg, 6% Zn as ZnO, 4.5% Fe as $FeSO_4$, 2% Mn as MnO, 0.5% Cu as $CuSO_4$, 0.3% I as $Ca(IO_3)2(H_2O)$, and 0.05% Co as $CoCO_3$.

[4] Premix contained 1,500 IU of vitamin A, 3,000 IU of vitamin D, and 3.7 IU of vitamin E per g.

[5] Formulated to supply 200 mg per steer daily monensin (Rumensin, Elanco Animal Health, Greenfield, IN).

[6] Dietary DM content prior to addition of water. Water added to diet DM to 60% across treatments.

[7] Diets were formulated to contain equal concentrations of Na across treatments.

Table 2. Effect of increasing dietary crude glycerin on intake, digestibility, and rate of fiber digestion.

	Dietary Treatments[1]					P-value[2]	
	0	4	8	12	SEM[3]	linear	quadratic
Intake, kg/d							
DM	8.46[a]	7.92[b]	8.17[ab]	8.39[ab]	0.51	0.79	0.04
OM	7.65[a]	7.17[b]	7.43[ab]	7.64[a]	0.46	0.96	0.04
NDF	6.01[a]	5.46[b]	5.37[b]	5.26[b]	0.34	< 0.01	0.06
Ruminal digestibility, %							
Apparent OM	37.7	41.2	42.2	43.9	3.1	0.15	0.77
True OM, corrected	43.4	47.1	47.6	49.2	3.0	0.16	0.71
NDF	53.6	51.2	50.2	53.7	3.2	0.98	0.33
Duodenal flow, kg/d							
Bacterial OM	0.44	0.42	0.40	0.40	0.03	0.16	0.63
Feed OM	4.32	3.77	3.89	3.86	0.28	0.12	0.20
Total OM	4.76	4.19	4.29	4.26	0.30	0.10	0.21
NDF	2.79	2.57	2.68	2.39	0.23	0.10	0.82
Post-ruminal digestibility, %							
OM	37.7	37.3	31.6	28.5	4.2	0.14	0.75
NDF	20.7	24.6	18.0	0.00	8.8	0.05	0.13
Fecal output, kg/d							
OM	2.94	2.62	2.85	3.00	0.23	0.83	0.24
NDF	2.26	2.03	2.18	2.40	0.20	0.58	0.20
Total apparent digestion, %							
OM	61.6	62.9	61.0	60.4	2.7	0.75	0.73
NDF	62.6	61.9	58.2	53.8	3.2	0.08	0.58
Wheat straw *in situ*[5]							
Rate, %/h	3.44	4.59	4.37	4.13	0.47	0.28	0.13
Extent at 96 hour, %	55.5	55.7	57.6	55.8	1.4	0.82	0.34
Soy hulls *in situ*[6]							
Rate, %/h	5.31	5.72	5.63	5.57	0.44	0.60	0.51
Extent at 96 hour, %	97.3	97.2	97.9	97.7	0.2	0.07	0.59

[1] 0 = 0% dietary crude glycerin; 4 = 4% dietary crude glycerin; 8 = 8% dietary crude glycerin; 12 = 12% dietary crude glycerin (DM basis).

[2] Linear and quadratic contrasts for increasing crude glycerin concentration.

[3] Standard error of the mean for crude glycerin inclusion.

[4] Calculated as: Bacterial OM flow / (OM intake × true OM ruminal digestibility)

[5] *In situ* NDF disappearance of wheat straw; Rate = fractional degradation rate of potentially digestible fraction of NDF.

[6] *In situ* NDF disappearance of soy hulls. Rate = fractional degradation rate of potentially digestible fraction of NDF.

[ab] Means within rows having different superscripts differ at $P \leq 0.05$.

Table 3. Fold change in selected ruminal microbial species abundance in response to increasing crude glycerin inclusion in high-forage diets.

	Dietary Treatment[1]					*P*-value[2]	
Species,	0	4	8	12	SEM[3]	linear	quadratic
Anaerovirbrio lipolytica	1.00	3.73	15.67	13.69	0.81	< 0.01	0.18
Butyrivibrio fibrosolvens	1.00	0.54	1.41	0.86	0.77	0.83	0.91
Megasphaera elsdenii	1.00	1.59	5.35	2.02	1.18	0.27	0.52
Fibrobacter succinogenes	1.00	1.04	3.77	1.52	0.49	0.31	0.30
Selenomonas ruminantium	1.00	1.91	18.47	21.44	1.12	< 0.01	0.74

[1] 0 = 0% dietary crude glycerin; 4 = 4% dietary crude glycerin; 8 = 8% dietary crude glycerin; 12 = 12% dietary crude glycerin (DM basis).

[2] Linear and quadratic contrasts for increasing crude glycerin concentration.

[3] Standard error of the mean for crude glycerin inclusion.

Table 4. Fold change in selected duodenal microbial species abundance in response to increasing crude glycerin inclusion in high-forage diets.

	Dietary Treatment[1]					*P*-value[2]	
Species,	0	4	8	12	SEM[3]	linear	quadratic
Anaerovirbrio lipolytica	1.00	1.29	8.07	8.85	0.70	< 0.01	0.87
Butyrivibrio fibrosolvens	1.00	13.97	17.09	21.35	0.39	< 0.01	< 0.01
Megasphaera elsdenii	1.00	1.47	1.35	1.35	0.51	0.61	0.59
Fibrobacter succinogenes	1.00	0.82	0.99	1.13	0.33	0.87	0.90
Selenomonas ruminantium	1.00	1.11	4.02	4.33	0.42	< 0.01	0.97

[1] 0 = 0% dietary crude glycerin; 4 = 4% dietary crude glycerin; 8 = 8% dietary crude glycerin; 12 = 12% dietary crude glycerin (DM basis).

[2] Linear and quadratic contrasts for increasing crude glycerin concentration.

[3] Standard error of the mean for crude glycerin inclusion.

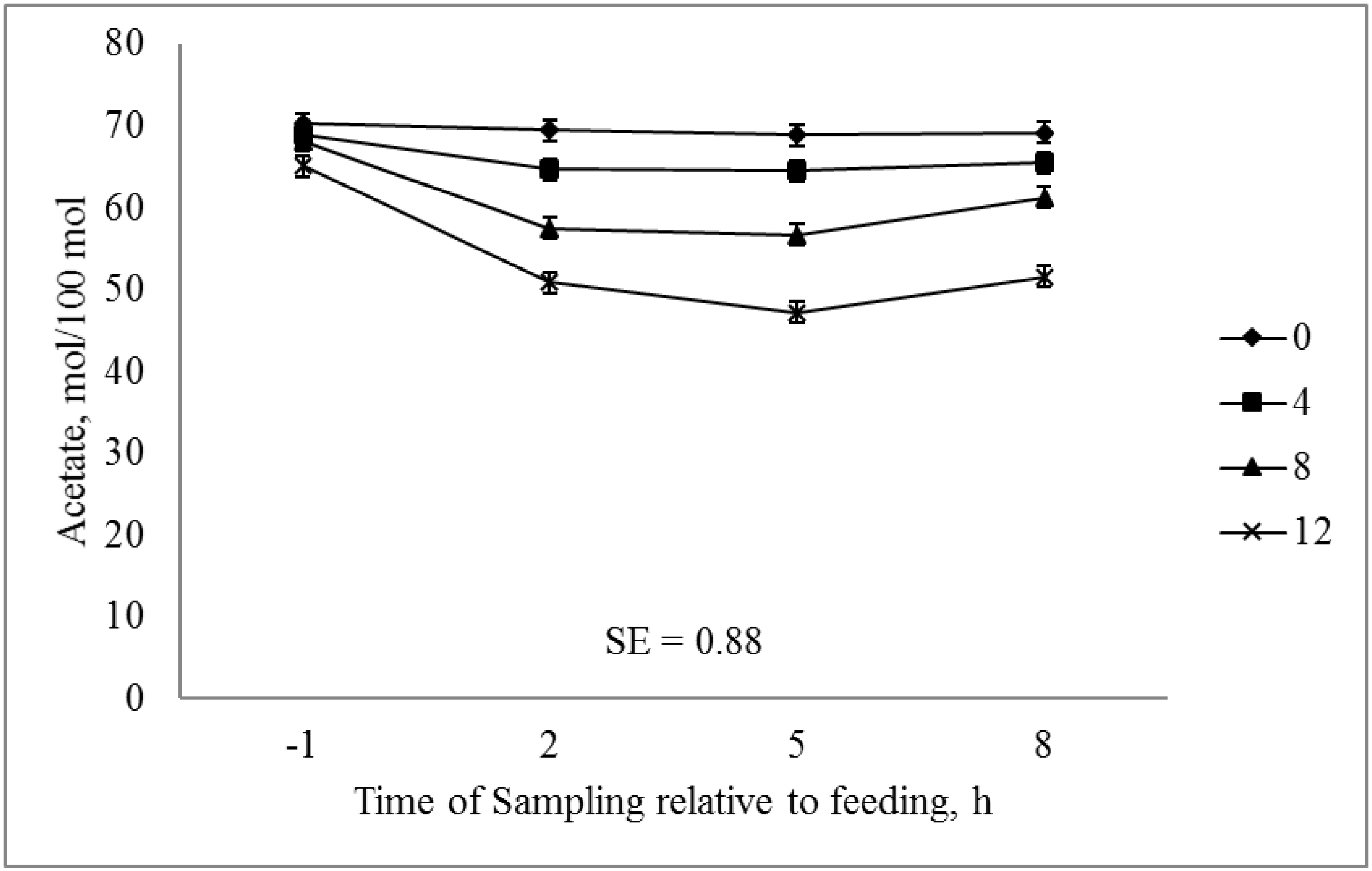

Figure 1. Ruminal acetate VFA proportions from samples collected at -1, 2, 5, and 8 h post feeding for treatments containing 0, 4, 8, or 12% dietary DM crude glycerin replacing soy hulls in high-forage diets.

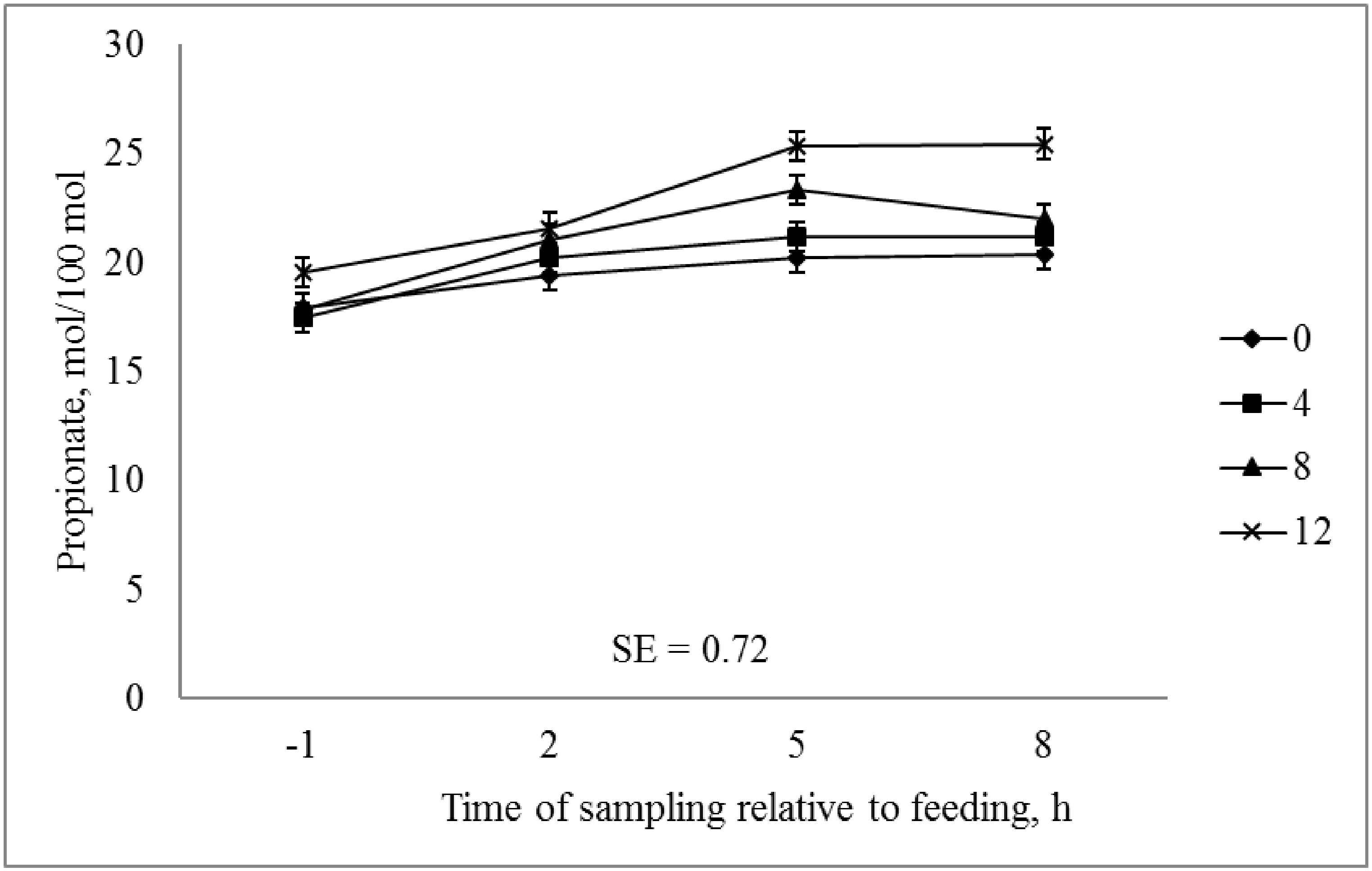

Figure 2. Ruminal propionate VFA proportions from samples collected at -1, 2, 5, and 8 h post feeding for treatments containing 0, 4, 8, or 12% dietary DM crude glycerin replacing soy hulls in high-forage diets.

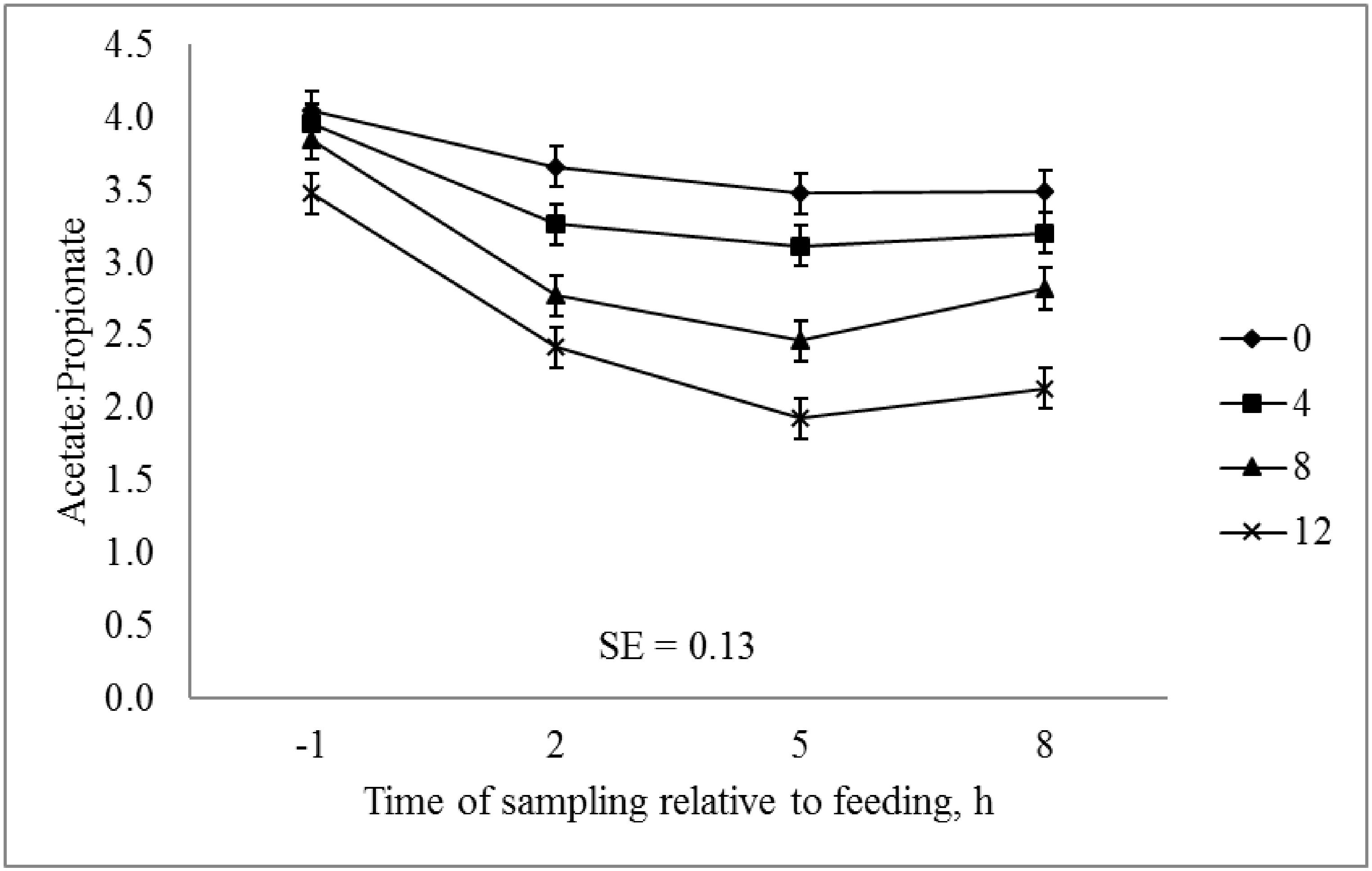

Figure 3. Ruminal acetate to propionate ratio from samples collected at -1, 2, 5, and 8 h post feeding for treatments containing 0, 4, 8, or 12% dietary DM crude glycerin replacing soy hulls in high-forage diets.

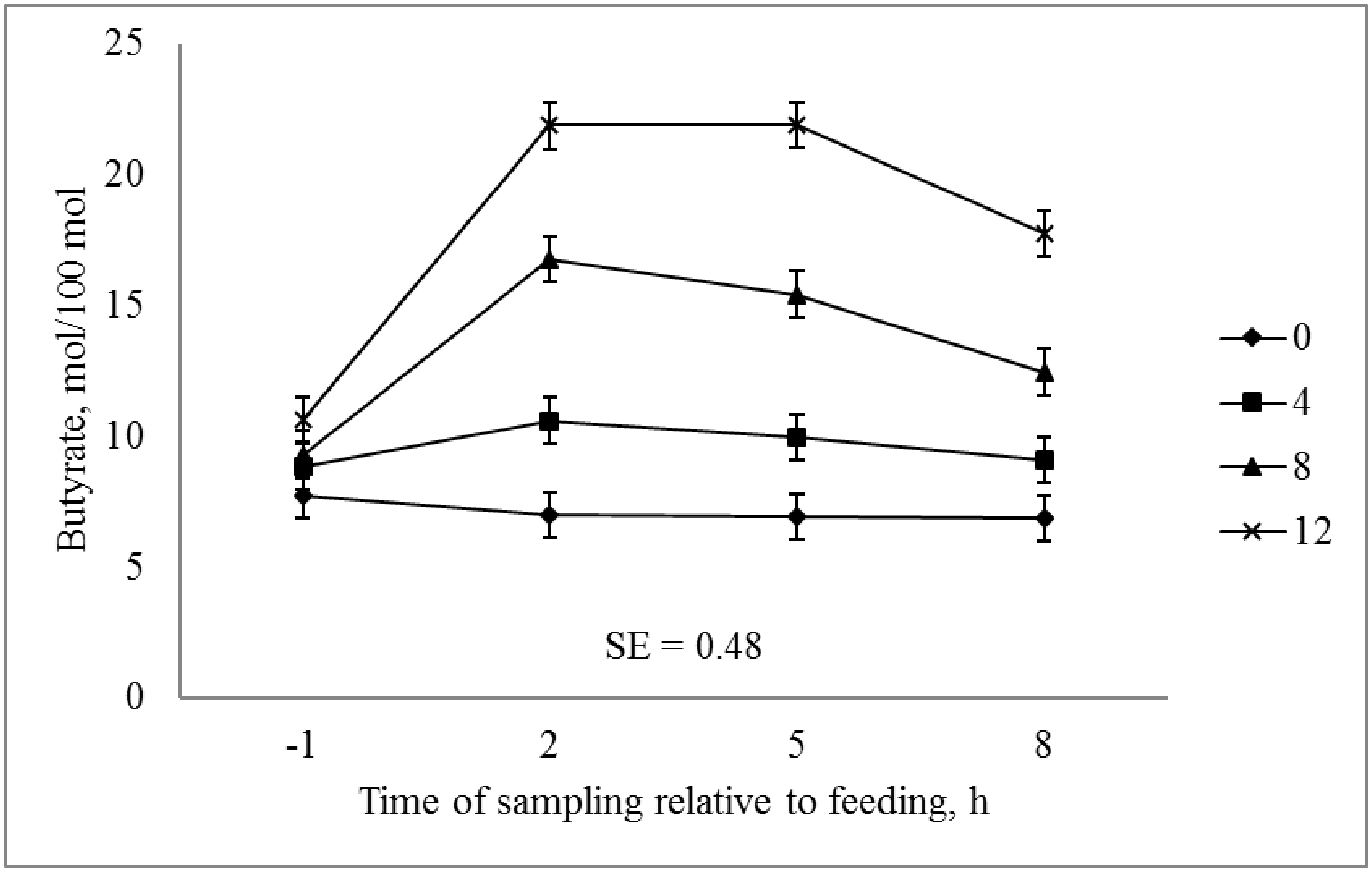

Figure 4. Ruminal butyrate VFA proportions from samples collected at -1, 2, 5, and 8 h post feeding for treatments containing 0, 4, 8, or 12% dietary DM crude glycerin replacing soy hulls in high-forage diets.

CHAPTER III

Effect of winter distillers grains supplementation on spayed heifer performance, carcass characteristics, and system profitability[1].

R. G. Bondurant*, B. L. Nuttelman*, C. J. Bittner*, T. K. Klopfenstein*, and J. C. MacDonald, PAS*[1].

[*]Department of Animal Science, University of Nebraska, Lincoln, NE 68583-0908

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ABSTRACT

A two-yr study was conducted utilizing 220 spayed heifers each yr (yr 1 BW = 227, SD = 21 kg; yr 2 BW = 240, SD = 23 kg) to determine the optimal level of modified distillers grains plus solubles (MDGS) supplementation during winter grazing. Treatments included the supplementation of MDGS at 1.36 (LOW), 2.27 (MED), and 3.18 (HIGH) kg/heifer daily during the winter corn residue grazing. Heifers grazed smooth bromegrass in the spring, native range during the summer and were finished on a common diet. In both yr, ending BW and ADG for the winter phase increased linearly ($P < 0.01$), and summer phase ADG decreased linearly ($P < 0.01$) as winter supplementation level increased. In yr 1, there were no differences ($P \geq 0.27$) in finishing performance, total system ADG, and carcass characteristics among treatments. In yr 2, final BW linearly increased ($P = 0.04$) by 25 kg from LOW to HIGH. Finishing ADG and G:F were not different ($P \geq 0.25$). In yr 2, HCW increased linearly ($P = 0.04$) by 16 kg when increasing from LOW to HIGH. As supplementation increased, rib fat linearly increased ($P = 0.04$) and calculated yield grade tended to increase ($P = 0.10$) in yr 2. Year 1 total feedlot costs were not different ($P = 0.85$); yr 2 total feedlot costs increased quadratically ($P = 0.05$) from LOW to MED and decreased at HIGH. Total system cost linearly increased ($P \leq 0.02$) in both yr. In yr 1, neither live nor carcass-based revenue were different among treatments ($P = 0.72$) resulting in a linear decrease in profit ($P = 0.01$) due to winter supplementation. In yr 2 both live and carcass-based revenue increased linearly ($P = 0.02$) with increasing winter supplement. Although revenue increased with increasing supplementation level for yr 2, neither live nor carcass-based

profit were different among treatments ($P \geq 0.47$). Supplementing heifers at 3.18 kg/d MDGS during winter corn residue grazing has the potential to increase HCW but is not profitable under the economic assumptions applied to the date.

Key Words: distillers grains, profitability, spayed heifer, supplementation

INTRODUCTION

In 2011 through September 2013, grain prices increased substantially. During that time, corn grain varied from $4.56 to record highs at $8.22, averaging $6.50/25.4 kg (56 lb. bu) for the Omaha, NE cash market. Consequently, the cost to finish beef cattle increased as well due to concurrent increases in ration cost. One way to decrease the inputs of finishing cattle is the use of a long yearling system to add weight before feedlot entry (Rolfe, 2011; Griffin et al., 2012; Gillespie-Lewis et al., 2016). A long-yearling system not only adds body frame to the animal but also decreases the amount of time required in the feedlot to reach a desired market endpoint. By decreasing the time spent on feed, the total feedlot cost can be reduced through decreased total ration fed and daily yardage expense. Utilizing distillers grains products during backgrounding is a common practice to provide supplemental protein and energy once protein needs of the animal are met (MacDonald et al., 2007; Loy et al., 2008; Griffin et al., 2012). While Rolfe (2011) and Watson et al. (2012) evaluated supplementing steers during the summer only, Gillespie-Lewis et al. (2016) evaluated both winter and summer supplementation before feedlot arrival. Gillespie-Lewis et al. (2016) determined that long yearling spayed heifers supplemented with distillers grains during the winter period, have similar live performance in the feedlot and have increased profit compared to those supplemented in both the winter and summer periods. The increase in profit is the result of an increase in live weight and HCW sold when heifers were fed a greater level of supplement during the winter grazing period. However, the optimal amount of winter supplementation to either meet protein requirements only or provide additional energy has not been defined in order to maximize animal performance and profitability.

The objective of this experiment was to determine the effects of distillers grains supplementation during the winter grazing period on heifer performance in the winter, summer, and finishing phases in a complete long yearling system. Carcass characteristics and system profitability were also evaluated to determine if level of winter supplementation affected HCW and profit.

MATERIALS AND METHODS

All animal care and management procedures were approved by the University of Nebraska-Lincoln Institutional Animal Care and Use Committee (IACUC # 902).

A study was conducted over 2 consecutive years utilizing 220 crossbred spayed heifers (yr 1 BW = 227, SD = 21 kg; yr 2 BW = 240, SD = 23 kg) per yr. In both yr, 4 heifers were removed from the study due to illness or lameness issues (foot rot), resulting in 216 total heifers utilized per yr. The study consisted of 3 winter supplement treatments with 8 replications per treatment each yr (9 heifers per replication). In each yr, before initiation of the experiment, heifers were purchased in the fall, transported to the University of Nebraska Agricultural Research and Development Center (**ARDC**) feedlot near Mead, Nebraska, and processed within 24 hours of arrival. Upon receiving, BW was recorded and heifers were vaccinated for the prevention of *infectious bovine rhinotracheitis virus*, *bovine virus diarrhea*, *parainfluenza* (PI_3), and *bovine respiratory syncytial virus* (BoviShield Gold 5, Zoetis Inc., Kalamazoo, MI) and *Haemophilus somnus* (Ultrabac 7/Somubac, Zoetis Inc.) and a parasiticide was injected (Dectomax, Zoetis, Inc.). After initial processing, heifers grazed cool season bromegrass for approximately 30-d. Approximately two weeks after initial receiving, heifers were re-vaccinated with a second dose of viral, bacterial, and clostridial vaccines (BoviShield Gold 5, Ultrabac 7/Somubac) and vaccinated with Piliguard Pinkeye-1 (Merck Animal Health, Madison, NJ) to prevent against infectious bovine keratoconjunctivitis.

Winter Phase

After the 30-d receiving period, heifers were placed in feedlot pens and limit-fed a diet of 50% alfalfa hay (diet DM), 50% Sweet Bran (Cargill Corn Milling, Blair, NE) at 2% BW per day for 5 consecutive days before a 2-d weight collection to minimize variation in gut fill (Watson et al., 2013). Heifers were weighed using a Silencer hydraulic squeeze chute (Dubas Equipment, Fullerton, NE) with a scale readability to the nearest 0.45 kg. The 2-d BW average served as initial BW for winter phase and growing system. At initiation of the trial, heifers were stratified by BW and assigned randomly to winter supplementation level of 1.36 (**LOW**), 2.27 (**MED**), or 3.18 kg DM (**HIGH**) modified distillers grains plus solubles (**MDGS**) per heifer daily. The MDGS fed in this study contained 31% CP (DM basis). Additionally, heifers were provided a supplement at 0.11 kg per heifer daily which contained a vitamin and trace mineral premix and 200 mg per heifer daily monensin (Rumensin 90, Elanco Animal Health, Indianapolis, IN). The premix was formulated to provide 1,500 IU of vitamin A, 3,000 IU of vitamin D, 3.7 IU of vitamin E per g daily, and 10% Mg, 6% Zn, 4.5% Fe, 2% Mn, 0.5% Cu, 0.3% I, and 0.05% Co daily. The MDGS and 0.11 kg/heifer supplement was mixed in a truck and fed in metal bunks providing a minimum of 46 cm per heifer. Heifers grazed within the three respective winter treatment groups on corn residue for the winter phase of backgrounding system at the ARDC from late fall to early spring. Stocking rate for each field was calculated assuming 7.26 kg DM corn residue per 25.4 kg corn (56 lb bushel) harvested per acre (as-is basis). Appropriate stocking rates were applied to assure equal residue availability across treatment groups during the backgrounding phase. Heifers were implanted with 36 mg zeranol (Ralgro, Merck Animal Health) on d-1 of the trial. For both years, heifers were surgically spayed by a veterinarian using the Kimberling-Rupp procedure (Rupp and Kimmerling, 1982) approximately half way through the winter phase. After spaying, heifers were held within pens overnight and turned back onto corn residue the following day. In yr 1, heifers grazed corn residue for 154 d. In yr 2, heifers grazed corn residue for 139 d.

Summer Phase

Heifers were removed from corn residue, placed in pens and limit-fed a common diet (DM basis) of 50% alfalfa hay, 50% Sweet Bran for 5 consecutive days with a 2-d BW collected to serve as the initial summer BW. Ending BW for the winter phase was calculated as the average of the 2-d BW minus 0.454 kg for each day heifers were fed the limit-fed diet to correct for weight gain during those 6 d. Heifers were implanted with 40 mg trenbolone acetate and 8 mg estradiol (Revalor-G, Merck Animal Health) and grazed smooth brome grass for 45 and 44 d (yr 1 and yr 2, respectively). After grazing smooth brome grass, heifers were branded, given insecticide pour-on (Standguard, Elanco Animal Health), and a pink-eye vaccine (Piliguard, Merck Animal Health), and were transported approximately 330 km (205 miles) to UNL Barta Brothers Ranch near Rose, Nebraska to graze native Sandhills range. Approximately 1 month after arrival to Barta Brother's Ranch, heifers received an insecticide ear tag (yr 1 - CyLence Ultra, Bayer, Shawnee Mission, KS; yr 2 – XP-820, Y-Tex Corporation, Cody, WY) to aid in fly control. A deferred rotational grazing system was utilized to allow dominant, warm-season grasses additional growing time without grazing pressure (Volesky et al., 2004 and Schacht et al., 2011). Based on previous research with unsupplemented heifers on Nebraska Sandhills range (Gillespie-Lewis et al., 2016), pastures were stocked at 1.59 animal unit months (**AUM**) per hectare (0.64 AUM/acre). The first pasture of the rotation was grazed to utilize 75% of the available forage (AUM), the second pasture to 100% AUM, and the third pasture at 125% AUM. Order of pastures grazed was alternated between years by using the first grazed pasture for yr 1 as the last grazed pasture in yr 2. In yr 1, heifers grazed native range for 96 d. In yr 2, heifers grazed native range for 118 d. Heifers grazed a shorter period of time in yr 1 because the Sandhills area of Nebraska was recovering from a previous year's drought and forage was limiting (Table 2). This equated to a total summer grazing phase of 141 d for yr 1 and 162 d for yr 2.

Finishing Phase

Upon completion of summer grazing, heifers were transported to Northeast Research and Extension Center near Concord, Nebraska. At the facility, heifers were limit-fed a common diet (DM basis) of 50% alfalfa hay, 50% Sweet Bran for 5 consecutive days with a 2-d BW collected. The average of the 2-d BW, corrected for limit-fed BW gain, served as the ending BW for the summer phase. The average of the 2-d limit fed BW served as the initial BW for the finishing phase. Heifers were assigned randomly to pen within winter treatment and implanted with 200 mg trenbolone acetate, 20 mg estradiol (Revalor-200®, Merck Animal Health) on d 1. Heifers were adapted to a common finishing diet containing 23.5% dry-rolled corn, 23.5% high moisture corn, 40% Sweet Bran, 9% ground hay, and 4% supplement (DM basis, Table 1). In yr 1 the dietary hay source was oat hay while in yr 2 the hay source was alfalfa. The supplement was formulated to provide minimum of 13.5% CP, Ca:P of 2:1, 450 mg monensin (Rumensin, Elanco Animal Health), and 90 mg tylosin (Tylan, Elanco Animal Health) per heifer daily and contained a trace mineral and vitamins A, D, and E package. The supplement was mixed and bagged at the University of Nebraska feed mill located near Mead, NE and transported to the Northeast Research and Extension Center feedlot. Heifers were fed for 113 d in yr 1 and 127 d in yr 2. In both years, all heifers were harvested on the same day at Greater Omaha Packing Co. (Omaha, NE). On day of harvest, HCW was recorded. Heifer final BW was calculated using individual HCW and a 63% common dress. Following a 48-h chill, carcass measurements including 12th rib fat thickness, LM area, and marbling score were collected. Yield grade was calculated as: Calculated YG (**YG**) = (2.5 + (0.98 x 12th rib fat thickness, cm) – (0.05 x LM area, cm^2) + (0.2 x KPH, %) + (0.0084 x HCW, kg)), with KPH assumed to be a constant 2.5% (USDA, 1997).

Economic Analyses

Long yearling system input assumptions were applied to each treatment group with respect to the number of days spent in each phase within the production system for yr 1 and yr 2 (Table 3). All prices were retrieved from the Livestock Marketing Information Center (Lakewood, CO) which summarizes data generated by USDA market reports. Using the Nebraska weekly feeder cattle summary, a feeder purchase price of $202.93/45.4 kg was calculated from a 5-yr November average price received from 2011 to 2015 for 182 to 272 kg heifers sold.

Winter and Summer Phases

Winter corn residue grazing cost was modified from Johnson (2013) and heifers were charged at $0.35 per heifer per day. Corn price was calculated to be $5.42/25.4 kg ($5.42/as-is bushel) based on an average weekly Omaha, NE cash price from a 5-yr September average price for 2011 to 2015. Utilizing the average price received for distillers grains in Nebraska for September 2011 – September 2015, the price was determined as 90% the value of corn (assuming 84.5% DM) on a DM basis during that time, which equated to $206.17/908 kg or $0.103/0.454 kg of MDGS (DM) fed during the winter. Total winter cost included the corn residue grazing cost plus the MDGS supplement cost for each treatment. Summer pasture rent was included at $0.90 per heifer per day grazed (modified from Johnson, 2013). Because no treatments were applied during the summer, costs were the same for all treatments within yr.

Finishing Phase

Heifers were charged a yardage fee of $0.45 per day for both years. Because the same hay source was not utilized between each yr (yr 1 oat hay; yr 2 alfalfa hay), the finishing ration for yr 1 was $179.11/908 kg while yr 2 was $181.39/908 kg. Ration price was determined using an average price received from monthly reported feedstuffs for September 2011 – September 2015. Total feedlot costs included yardage, feed cost, and other miscellaneous feedlot charges. Total cost per heifer included purchase price, total winter cost, and total feedlot cost.

Total revenue and profit for each treatment was calculated both live and carcass-based sale. Grid based marketing strategies were not evaluated in this experiment. Live heifer price ($138.33/45.4 kg) and base carcass price ($217.12/45.4 kg) received was determined using an average from the 5-Area Market fed heifer report for the months of January 2012 – January 2016. Total revenue included the price received per heifer either on a live or carcass-basis while profit was calculated by subtracting total cost (including purchase price) from the total revenue.

Statistical Analyses

All performance and economic data were analyzed using the GLIMMIX procedure of SAS (SAS Institute, Inc., Cary, N.C.). Winter supplementation level, yr, and winter supplementation level × yr interaction were included in the model as fixed effects. Finishing pen within winter supplementation treatment (n = 8 per yr) was included as the experimental unit. Orthogonal contrasts were used to test linear and quadratic effects of winter supplementation level. Treatment effects or the interaction were considered a tendency at $P < 0.10$ and significant at $P < 0.05$. Because there were numerous winter supplementation level × yr interactions (Table 4) for both performance and economic analyses, the simple effects are presented within yr.

RESULTS AND DISCUSSION

Winter Phase

Initial BW was similar for each treatment, although heifers were lighter in yr 1 (227 kg) compared to yr 2 (240 kg). A significant treatment × yr interaction ($P < 0.01$) for winter ADG was noted, so the simple effects of winter supplementation amount are presented within yr. For both years, ADG linearly increased ($P < 0.01$) as MDGS supplementation increased (Table 5). In yr 1, heifers gained 0.69, 0.74, and 0.89 kg/d, while yr 2 heifers gained 0.65, 0.81, and 0.94 kg/d when supplemented LOW, MED, and HIGH amounts of MDGS (DM) daily, respectively. Jones et al. (2014) fed either MDGS or dried distillers grains plus solubles (**DDGS**) at 0.3, 0.7, and 1.1% of BW to steer calves on corn residue and noted a quadratic increase in ADG (0.70, 0.92, and 0.96 kg/d, respectively) as supplement increased, but no difference when comparing distillers grains type (DDGS vs. MDGS). However, when calves grazing corn residue were supplemented with DDGS at 0.3, 0.5, 0.7, 0.9, and 1.1% of BW, ADG increased linearly from 0.35 to 1.00 kg/d (Jones et al., 2015). The data reported by Jones et al. (2014) and Jones et al. (2015) are similar to the current study where increased supplemental distillers grains delivers increased ADG on corn residue.

Due to increased ADG during winter corn residue grazing, ending BW for the winter increased linearly ($P < 0.01$) as supplementation amount increased. There was a significant treatment × yr interaction ($P = 0.02$) where heifers in yr 2 had increased ending winter BW due to greater response to supplement especially between LOW and MED compared to yr 1. In yr 1, heifers were 7 (MED) and 16 kg (HIGH) heavier than LOW supplemented heifers weighing 336 kg, while in yr 2, heifers were 23 (MED) and 16 kg (HIGH) heavier compared with LOW which weighed 330 kg. The estimated total MP requirements for yr 1 heifers were 492 (LOW), 584 (MED), and 684 g/d (HIGH) while yr 2 total MP requirements were 472 (LOW), 573 (MED), and 677 g/d (HIGH), respectively. The grazed corn residue plus MDGS supplement was estimated to provide 640 (LOW), 852 (MED), and 1064 g/d MP (HIGH), which equates to an excess of 148, 268, and 380 g/d MP for yr 1 and an excess of 168, 279, and 387 g/d MP for yr 2, LOW, MED, and HIGH respectively. Preceding the current study, Gillespie-Lewis et al. (2016) evaluated two levels of MDGS winter supplementation during winter corn residue grazing. In this study, a low level of supplement was provided to meet only protein requirements and a high level fed to meet protein requirements and provide additional energy. Gillespie-Lewis et al. (2016) observed increased ADG and final BW for heifers fed the high level of MDGS supplementation during the winter. This demonstrates that MDGS or DDGS can supply additional energy to a diet once protein requirements of the animal are satisfied. Similar results were reported in a meta-analysis conducted by Griffin et al. (2012) evaluating DDGS supplementation in forage-based diets. Griffin et al. (2012) observed that increasing DDGS supplementation increased ADG linearly and final BW quadratically. For the current study, the increase in heifer ADG and BW from both years as supplementation of MDGS increases would suggest that additional energy was supplied by the MDGS supplement for increased growth.

Summer Phase

There was no treatment × yr interaction ($P \geq 0.12$) for summer ADG or ending BW. During the summer phase for both yr, heifer ADG linearly decreased ($P < 0.01$) as winter supplementation increased (Table 5); however, yr 2 heifers had increased ADG compared to yr 1. In yr 1, summer ADG was lower at 0.36, 0.31, and 0.23 kg/d while yr 2 ADG was 0.54, 0.46, and 0.40 kg/d when MDGS was supplemented at LOW, MED, and HIGH in winter. In 2012 and during yr 1 grazing, the Sandhills area of Nebraska underwent a severe drought with decreased precipitation during the growing season (Table 2). The shortage of rainfall resulted in decreased forage quantity, thus the decreased ADG and total grazing days during yr 1 summer grazing phase. Heifers in yr 1 were removed from summer grazing earlier than intended due to limited forage growth. In yr 2, grazing conditions were more favorable providing an increase in ADG for all treatments as compared to yr 1. In Gillespie-Lewis et al. (2016), heifers supplemented with 0.91 and 2.3 kg MDGS daily during the winter and no summer supplement while grazing the Sandhills of Nebraska gained 0.65 and 0.54 kg/d, respectively. These daily gains are greater than yr 1 ADG but comparable to the gains in yr 2 of the current study.

The decrease in heifer summer ADG as winter supplementation increased is a result of compensatory gain response. This response to protein and/or energy restriction has been evaluated by many (Bohman, 1955; Wilson and Osbourn, 1960; Fox et al., 1972, and Drouillard et al., 1991) with the agreement that compensatory growth is characterized as an accelerated rate of growth after a period of restriction. In this study, the heifers supplemented the LOW level had the lowest plain of nutrition as compared to those heifers which were supplemented greater levels of MDGS. Consequently, those heifers which received the lowest amount of MDGS during the winter had the greatest ADG for the summer and the heifers supplemented the HIGH during the winter had lowest summer ADG. These results are similar to Gillespie-Lewis et al. (2016) where the heifers supplemented the lower level of MDGS in the winter had greater summer ADG than those heifers fed a higher level of MDGS during the winter.

When comparing heifer performance on total forage system (average of winter and summer), there was no difference in ADG ($P \geq 0.12$) or ending BW ($P \geq 0.36$) for yr 1. However, in yr 2 total forage system ADG increased linearly ($P < 0.01$) as winter supplementation increased (0.59, 0.62, and 0.64 kg/d, respectively). In yr 2, ending BW linearly increased ($P < 0.01$) from 415 kg for LOW to 433 kg for HIGH supplemented heifers. The treatment × yr interaction may suggest that supplementing HIGH during the winter has a potential to increase BW coming off summer range when grazing conditions are not limited as with yr 1. The results of yr 2 are similar to yr 1 data of Gillespie-Lewis et al. (2016) where the heifers supplemented a high level in the winter (2.3 kg MDGS daily) and no supplement in the summer had greater ADG and ending BW for the growing system compared to the low winter level (0.91 kg MDGS daily) with no summer supplementation.

Finishing Phase

There was no treatment × yr interaction for finishing ADG or final BW ($P \geq 0.14$, Table 4), therefore the simple effect of winter supplement level within yr will be discussed. For yr 1 heifers, there was no difference ($P = 0.69$) in final BW among supplementation level while in yr 2, final BW linearly increased ($P = 0.04$) from 591 (LOW) to 616 kg (HIGH) due to winter supplementation (Table 6). Gillespie-Lewis et al. (2016) reported increases in heifer final BW when supplemented 2.3 kg DM MDGS (similar to current study MED) during winter backgrounding compared to final BW of heifers supplemented 0.91 kg DM MDGS. In a similar study conducted by Lewis et al. (1989) evaluating 3 levels of winter gain and their effect on subsequent pasture and finishing performance, finishing DMI, ADG, and G:F were not different while those steers that had the higher gains in the winter had increased final BW.

The treatment × yr interaction was not significant ($P = 0.33$) for finishing DMI, therefore the simple effect of winter supplementation level within yr will be discussed. While yr 1 DMI was not different among treatments ($P \geq 0.90$), there was a quadratic tendency ($P = 0.07$) for DMI to increase from 13.5 (LOW) to 13.9 (MED) and decrease to 13.5 kg (HIGH) in yr 2. The results of the current study coincide with previous research. The meta-analysis by Griffin et al. (2012) and study by Gillespie-Lewis et al. (2016) evaluating different supplementation amounts in forage-based backgrounding reported no difference in finishing DMI. However, Downs et al. (1998) reported increased finishing DMI with increasing winter backgrounding supplementation.

The treatment × yr interaction was not significant ($P \geq 0.25$) for finishing ADG nor G:F. For both yr 1 and 2, heifer ADG and G:F were not different ($P \geq 0.25$) during the fall finishing phase due to winter supplementation. In previous research supplementing either spayed heifers or steers during a summer backgrounding phase prior to finishing (Rolfe, 2011; Griffin et al., 2012; Gillespie-Lewis et al., 2016), ADG and G:F were decreased in the feedlot as supplementation increased. This decrease in feedlot ADG and G:F were attributed to compensatory gain. Because the spayed heifers in the current study were not supplemented during the summer phase before the feedlot, ADG and G:F were similar among winter treatments. The compensatory effects caused by varying levels of winter supplement likely occurred during the summer only and were not carried into the feedlot.

There was no treatment × yr interaction ($P = 0.13$) for total system ADG (average of winter, summer, and finishing phases). Total system ADG was not different among treatments ($P = 0.91$) for yr 1. Contrary to yr 1, total system ADG for yr 2 linearly increased ($P = 0.02$) from 0.83 to 0.89 kg/d as MDGS supplementation increased during the previous winter from LOW to HIGH. The increase in ADG for yr 2 is attributed to the increased gains during finishing for MED and HIGH compared to LOW (1.46 and 1.45 vs. 1.39 kg/d, respectively).

Carcass Characteristics

There was marginal significance for treatment × yr interaction for HCW ($P \leq 0.14$) so the simple effects of winter supplementation within yr will be discussed. While there were no differences in HCW for yr 1 ($P = 0.67$), HCW in yr 2 increased linearly ($P = 0.04$) from 372 to 388 kg as winter supplementation increased from LOW to HIGH (Table 6). Both Lewis et al. (1989) and Gillespie-Lewis et al. (2016) reported increases in HCW as calves were grown at greater daily rates or fed increased levels of supplement during winter backgrounding. It appears heifers in yr 2 of the current study retained the added weight gained during the winter through summer and into the feedlot as carcass weight because grazing conditions were not limiting growth, compared with yr 1 summer grazing limitations.

There were no differences ($P \geq 0.23$) in LM area or marbling score for either yr among treatments. There was marginal evidence ($P \leq 0.12$) for treatment × yr interaction to be significant for 12th rib fat thickness and calculated YG so the simple effects of winter treatment within yr will be discussed. In yr 1, there was no difference in 12th rib fat thickness or calculated YG among treatments ($P \geq 0.51$). However, there was a linear increase ($P = 0.04$) in 12th rib fat thickness and consequently a tendency for a linear increase in calculated YG ($P = 0.10$) as heifers were supplemented with increasing levels of MDGS in the winter phase in yr 2. Lewis et al. (1989) reported no difference in 12th rib fat thickness, quality grade, or YG as steers were grown at increasing rates during the previous winter. Rolfe (2011) and Gillespie-Lewis et al. (2016) described no differences in 12th rib fat thickness, marbling scores, or calculated yield grade due to winter supplementation rate.

System Profitability

Winter Phase

For all treatments, corn residue grazing cost was consistent within yr. During yr 1, corn residue grazing cost equated to $53.90 per heifer while in yr 2, it was $48.65 due to the difference in days grazed. In yr 1, total MDGS supplement cost linearly increased ($P < 0.01$) by $31.75 increments per heifer as amount fed increased from LOW ($47.63) to HIGH ($111.13; Table 7). In yr 2, winter supplement cost increased by $28.39 increments per heifer from $42.99 (LOW) to $100.30 (HIGH). This equates to roughly a

\$30 incremental increase in supplement cost as amount of MDGS given increased by 0.91 kg daily. Total winter costs linearly increased ($P < 0.01$) from \$101.53 (LOW) to \$165.03 (HIGH) for yr 1 and from \$91.64 (LOW) to \$148.95 (HIGH) for yr 2.

Summer Phase

Since there were no treatments applied during the summer phase, all heifers were grazed together regardless of previous winter treatment. Therefore, the grazing cost associated with the summer phase had no impact on the economic analyses because it was equal across treatments within yr. Summer grazing costs were \$126.90 per heifer (yr 1) and \$145.80 per heifer (yr 2).

Finishing Phase

There was no treatment × yr interaction for total feedlot cost ($P = 0.32$). Total feedlot costs, described in Table 6, were not different among treatments within yr ($P = 0.40$). However, total feedlot costs were greater for yr 2 due to 14 additional days on feed, increased DMI, and slightly increased basal diet cost. In yr 1, total feedlot costs averaged \$397.48 per heifer while in yr 2, feedlot costs averaged \$466.62 per heifer. Likewise, in an economic analysis conducted by Gillespie et al. (2016), winter supplementation had no effect on total feedlot costs.

Revenue and Profitability

The total cost associated per treatment included purchase cost, total winter cost, summer grazing cost, and total feedlot cost. There was no treatment × yr interaction for total cost per heifer ($P = 0.65$). Although purchase cost varied by yr due to differences in initial BW, there were no differences ($P = 0.84$) in purchase cost among treatments for either yr. Due to the increase in winter supplement cost, there was a linear increase ($P <$ 0.01) in total cost per heifer in both years. In yr 1, total cost increased from $1647.30 (LOW) to $1696.11 per heifer (HIGH) while in yr 2, total cost increased from $1771.09 (LOW) to $1831.05 per heifer (HIGH).

There was marginal significance (P = 0.14) of a treatment × yr interaction for live gross revenue and carcass-based revenue due to differences in HCW. In both yr, neither live revenue nor carcass-based revenue were different among winter treatments (P = 0.24). In yr 1, live revenue averaged $1835.90 per heifer while carcass-based revenue averaged $1815.40 per heifer. However, in yr 2, both live and carcass-based revenue increased linearly (P = 0.02) as winter supplement increased from LOW to HIGH. Live revenue increased from $1799.28 (LOW) to $1876.12 per heifer (HIGH) while carcass-based revenue increased from $1779.19 (LOW) to $1855.17 per heifer (HIGH). Revenue generated in yr 1 was not different because final BW and HCW were not different among treatments while in yr 2, the increase in final BW and HCW generated greater revenue as winter supplementation increased.

There was a tendency for an interaction of treatment × yr (P =0.07) for both live and carcass-based profit. While revenue generated for yr 1 was not different, both live and carcass-based profit decreased linearly (P = 0.01) as winter supplementation increased from LOW to HIGH. Live profit decreased from $191.10 (LOW) to $131.15 (HIGH) and carcass-based profit decreased from $170.57 to $110.75 as winter supplement increased from LOW to HIGH. Even though revenue for yr 2 increased as supplementation amount increased, both live and carcass-based profits were not different among treatments ($P \geq 0.47$). Live profit increased numerically from $28.18 (LOW) to $45.07 per heifer (HIGH) while carcass-based profit numerically increased from $8.10 to $24.13 per heifer as winter supplement increased from LOW to HIGH. Although not significantly different, live and carcass-based profit increased in yr 2 due to additional final BW and HCW sold which overcame the additional feeding cost associated with increased supplementation amounts.

Similar results as yr 2 were described in Gillespie-Lewis et al. (2016) where revenue per heifer was $137.55 and $65.28 (yr 1 and 2, respectively) greater for heifers supplemented at 2.3 vs. 0.91 kg DM MDGS during winter backgrounding only. The authors attributed the additional revenue to the increased HCW in those heifers fed 2.3 kg MDGS/d. The additional revenue equated to an increase in profit of $87.56 and $52.89 per heifer (yr 1 and 2, respectively). In a pooled analysis evaluating supplementation rates during winter backgrounding by Gillespie-Lewis et al. (2015), similar profitability results were described. In the pooled analysis, calves supplemented at higher levels during the winter only had an average increase of $85.50 profit per head regardless of corn price and subsequently distillers grains price. However, due to variation in market conditions including increased corn and feeder cost, the economic analysis of the current study does not agree with the results of Gillespie-Lewis et al. (2015).

IMPLICATIONS

Supplementing spayed heifers with increasing amounts of MDGS during winter backgrounding supplies adequate protein and additional energy for growth. Level of winter supplementation had no effect on finishing ADG or G:F when backgrounded on summer grass without supplement prior to feedlot arrival. Supplementing 3.18 kg/heifer MDGS daily during the winter increased total system gain by 0.06 kg/d compared to supplementing 1.36 kg/heifer MDGS daily when summer grazing was not limited. Supplementing heifers at 3.18 kg/heifer MDGS daily during winter corn residue grazing has the potential to increase HCW by 16 kg, which increases carcass-based revenue generated by $75.98 (yr 2). The increase in revenue has the potential to offset increased winter supplementation costs and thus increase carcass-based profit by $16.02 per heifer. Careful consideration should be taken to evaluate current corn and cattle market conditions to determine if the backgrounding system can maintain profitability with retained ownership.

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Table 1. Composition of finishing diets fed to spayed heifers in a two-yr study evaluating three levels of modified distillers grains plus solubles supplement during winter corn residue backgrounding phase.

Ingredient[1],	Yr 1	Yr 2
Dry-rolled corn	23.5	23.5
High-moisture corn	23.5	23.5
Sweet Bran[2]	40.0	40.0
Corn silage	5.0	-
Oat hay	4.0	-
Alfalfa hay	-	9.0
Supplement[3],		
Fine-ground corn	1.871	1.871
Limestone	1.640	1.640
Salt	0.300	0.300
Tallow	0.100	0.100
Beef trace minerals[4]	0.050	0.050
Vitamins A-D-E[5]	0.015	0.015
Monensin[6]	0.0165	0.0165
Tylosin[7]	0.0075	0.0078

[1] Ingredients presented as % diet DM.
[2] Cargill Corn Milling, Blair, Nebraska.
[3] Included at 4% total diet DM for yr 1 and yr 2.
[4] Premix contained 10% Mg, 6% Zn, 4.5% Fe, 2% Mn, 0.5% Cu, 0.3% I, and 0.05% Co.
[5] Premix contained 1,500 IU of vitamin A, 3,000 IU of vitamin D, and 3.7 IU of vitamin E per g.
[6] Rumensin 90, Elanco Animal Health, Indianapolis, IN. Formulated to provide 450 mg per heifer daily.
[7] Tylan 40, Elanco Animal Health, Indianapolis, IN. Formulated to provide 90 mg per heifer daily.

Table 2. Cumulative precipitation (cm) by month at Rose, NE for previous and current study years growing seasons.

Month,	30-yr	2012	2013 (yr 1)	2014 (yr 2)
Oct – March	5.08	5.70	2.84	1.96
April	7.78	9.76	3.12	3.46
May	10.92	11.15	6.93	4.60
June	14.85	11.62	9.77	10.09
July	17.32	11.92	13.73	11.36
August	19.48	13.74	15.64	15.53
September	21.38	14.23	17.24	16.55

Table 3. Economic assumptions applied to long yearling heifers provided modified distillers grains plus solubles while grazing winter corn residue, followed by grazing summer pasture, and fed common ration during finishing.

Item[1],	
Feeder calf price, \$/45.4 kg[2]	202.93
Live fed price, \$/45.4 kg[2]	138.33
Base carcass price, \$/45.4 kg[2]	217.12
Corn price, \$/25.4 kg[3]	5.42
MDGS, \$/908 kg[4]	206.17
Corn residue rent, \$/heifer daily[5]	0.35
Summer pasture rent, \$/heifer daily[5]	0.90
Feedlot yardage, \$/heifer daily	0.45
Yr 1 finishing ration, \$/908 kg[6]	179.11
Yr 2 finishing ration, \$/908 kg[6]	181.39

[1] Pricing data retrieved from Livestock Marketing Information Center, Lakewood, CO. Utilizing compiled USDA market data from September 2011 – September 2015.

[2] Price paid or received using a 5-year average from the 5-Area Market Summary.

[3] Price/25.4 kg (\$/bushel) on DM basis using 5-year market average from Omaha, NE.

[4] Price/908 kg on DM basis using 5-year market average from Omaha, NE. Calculated at 90% value of corn on DM basis; Corn assumed 84.5% DM.

[5] Prices include animal care and supplement delivery cost. Modified from Johnson (2013).

[6] Ration cost per 908 kg on DM basis.

Table 4. *P*-values for response variables from winter supplementation of spayed heifers.

Item,	Treatment x yr	Treatment	Year
Forage system			
Stalk initial BW	0.73	0.84	< 0.01
Stalk ADG	< 0.01	< 0.01	0.04
Stalk ending BW	0.02	< 0.01	0.06
Summer initial BW	0.02	< 0.01	0.55
Summer ADG	0.58	< 0.01	< 0.01
Summer ending BW	0.12	0.01	< 0.01
Finishing performance			
Finishing initial BW	0.11	0.01	< 0.01
Finishing ADG	0.38	0.54	< 0.01
DMI	0.33	0.43	< 0.01
G:F	0.25	0.75	< 0.01
Final BW	0.14	0.24	0.57
Total ADG	0.13	0.11	< 0.01
Carcass characteristics			
HCW	0.14	0.25	0.57
LM area	0.86	0.25	< 0.01
12th rib fat thickness	0.12	0.16	< 0.01
Marbling score	0.75	0.30	< 0.01
Calculated YG	0.10	0.46	< 0.01
Economic analyses			
Purchase cost	0.72	0.84	< 0.01
Supplement cost	< 0.01	< 0.01	< 0.01
Feed cost	0.31	0.38	< 0.01
Feedlot cost	0.32	0.40	< 0.01
Total cost	0.65	< 0.01	< 0.01
Live revenue	0.14	0.24	0.58
Carcass revenue	0.14	0.24	0.58
Live profit	0.07	0.34	< 0.01
Carcass profit	0.08	0.32	< 0.01

Table 5. Winter, summer and total forage system performance of spayed heifers provided three levels of modified distillers grains plus solubles supplement during winter corn residue backgrounding phase.

	Treatments[1]				*P*-value	
Item,	LOW	MED	HIGH	SEM	Linear	Quadratic
Winter, yr 1[2]						
Initial BW, kg	228	227	225	4	0.24	0.81
ADG, kg/d	0.69[c]	0.74[b]	0.89[a]	0.01	< 0.01	0.17
Ending BW, kg	336[c]	343[b]	359[a]	2	< 0.01	0.22
Winter, yr 2[2]						
Initial BW, kg	240	241	240	3	0.95	0.72
ADG, kg/d	0.65[c]	0.81[b]	0.94[a]	0.01	< 0.01	0.16
Ending BW, kg	330[c]	353[b]	369[a]	4	< 0.01	0.39
Summer, yr 1[3]						
ADG, kg/d	0.36[a]	0.31[b]	0.23[c]	0.01	< 0.01	0.32
Summer, yr 2[3]						
ADG, kg/d	0.54[a]	0.46[b]	0.40[c]	0.01	< 0.01	0.64
Total forage system, yr 1[4]						
ADG, kg/d	0.54	0.56	0.54	0.01	0.85	0.12
Ending BW, kg	393	393	397	3	0.36	0.67
Total forage system, yr 2[4]						
ADG, kg/d	0.59[c]	0.62[b]	0.64[a]	0.01	< 0.01	0.69
Ending BW, kg	415[c]	427[b]	433[a]	4	< 0.01	0.59

[1] Treatments applied during the winter corn residue grazing phase; LOW = supplemented with 1.36 kg DM modified distillers grains plus solubles (MDGS), daily; MED = 2.27 kg DM MDGS, daily; HIGH = 3.18 kg DM MDGS, daily.

[2] Winter = corn stalk residue grazing for 154 d in yr 1 and 139 d in yr 2.

[3] Summer = smooth bromegrass grazing for 45 and 44 d (yr 1 and yr 2, respectively) followed by native range grass for 96 d and 118 d (yr 1 and yr 2, respectively).

[4] Total forage system = average heifer performance from start of winter phase to end of summer phase.

Table 6. Finishing performance and carcass characteristics of spayed heifers provided three levels of modified distillers grains plus solubles supplement during previous winter corn residue backgrounding phase.

	Treatments[1]				*P*-value	
Item,	LOW	MED	HIGH	SEM	Linear	Quadratic
Performance, yr 1						
Final BW, kg[2]	603	604	600	6	0.69	0.71
DMI, kg/d	12.9	12.9	12.9	0.2	0.91	0.90
ADG, kg	1.87	1.88	1.80	0.05	0.30	0.44
G:F, kg/kg	0.144	0.145	0.139	0.003	0.32	0.36
Total system ADG, kg[3]	0.92	0.93	0.92	0.01	0.91	0.63
Carcass characteristics, yr 1						
HCW, kg	380	381	378	4	0.67	0.70
LM area, cm^2	88.4	89.0	89.0	0.6	0.60	0.56
12th rib fat thickness, cm	1.35	1.37	1.35	0.05	0.85	0.59
Marbling Score	517	498	508	10	0.50	0.27
Calculated YG	3.14	3.15	3.08	0.07	0.51	0.59
Performance, yr 2						
Final BW, kg[2]	591[b]	612[a]	616[a]	8	0.04	0.42
DMI, kg/d	13.5	13.9	13.5	0.2	0.86	0.07
ADG, kg	1.39	1.46	1.45	0.05	0.36	0.44
G:F, kg/kg	0.102	0.104	0.106	0.002	0.25	0.98
Total system ADG, kg[3]	0.83[b]	0.87[a]	0.89[a]	0.02	0.02	0.44
Carcass characteristics, yr 2						
HCW, kg	372[b]	385[a]	388[a]	5	0.04	0.43
LM area, cm^2	84.5	86.5	85.8	0.06	0.31	0.23
12th rib fat thickness, cm	1.42[a]	1.42[a]	1.63[b]	0.05	0.04	0.19
Marbling Score	561	548	568	12	0.69	0.28
Calculated yield grade[4]	3.32	3.31	3.58	0.10	0.10	0.29

[1] Treatments applied during the winter corn residue grazing phase; LOW = supplemented with 1.36 kg DM modified distillers grains plus solubles (MDGS), daily; MED = 2.27 kg DM MDGS, daily; HIGH = 3.18 kg DM MDGS, daily.

[2] Final BW = carcass adjusted using common DP of 63%.

[3] Total system ADG = average heifer performance of winter phase + summer phase + finishing performance

[4] Calculated as: YG = 2.5 + (0.98 x 12th rib fat thickness, cm) – (0.05 x LM area, cm^2) + (0.2 x KPH, %) + (0.0084 x HCW, kg); USDA, 1997.

Table 7. Economic analysis on spayed heifer performance when fed three levels of modified distillers grains plus solubles supplement during winter corn residue backgrounding.

	Treatments[2]				*P*-value	
Item[1],	LOW	MED	HIGH	SEM	Linear	Quadratic
Inputs, yr 1						
Purchase cost[3]	1020.61	1011.52	1007.10	10.97	0.39	0.86
Winter supplement	47.63	79.38	111.13	0.00	< 0.01	-
Total winter cost[4]	101.53	133.28	165.03	0.00	< 0.01	0.96
Total feedlot cost[5]	398.26	397.11	397.08	4.43	0.85	0.92
Total cost[6]	1647.30	1668.81	1696.11	13.65	0.02	0.86
Outputs, yr 1						
Live revenue[7]	1838.39	1842.04	1827.26	22.16	0.72	0.74
Carcass revenue[8]	1817.87	1821.48	1806.48	21.91	0.72	0.74
Live profit[9]	191.10	173.23	131.15	16.38	0.01	0.55
Carcass profit[10]	170.57	152.67	110.75	16.19	0.01	0.55
Inputs, yr 2						
Purchase cost[3]	1071.34	1077.97	1072.71	10.97	0.93	0.66
Winter supplement	42.99	71.64	100.30	0.00	< 0.01	-
Total winter cost[4]	91.64	120.29	148.95	0.00	< 0.01	0.97
Total feedlot cost[5]	462.31	473.96	463.58	4.43	0.84	0.05
Total cost[6]	1771.09	1818.03	1831.05	13.65	< 0.01	0.32
Outputs, yr 2						
Live revenue[7]	1799.28	1862.39	1876.12	22.16	0.02	0.37
Carcass revenue[8]	1779.19	1841.60	1855.17	21.91	0.02	0.37
Live profit[9]	28.18	44.36	45.07	16.38	0.47	0.70
Carcass profit[10]	8.10	23.57	24.13	16.19	0.49	0.71

[1] All economic analyses items presented as $ per heifer.

[2] Treatments applied during the winter corn residue grazing phase; LOW = supplemented with 1.36 kg DM modified distillers grains plus solubles (MDGS), daily; MED = 2.27 kg DM MDGS, daily; HIGH = 3.18 kg DM MDGS, daily.

[3] Calculated using Nebraska livestock market sales in 45.4 kg weight groups multiplied by initial BW/45.4.

[4] Total winter supplement cost + winter cornstalk grazing rent.

[5] Total feedlot costs including feed, veterinary and misc, yardage, trucking, death loss, and interest.

[6] Total costs including purchase cost, total winter costs, summer pasture rent (yr 1 = $126.90/heifer; yr 2 = $145.80/heifer), and total feedlot costs.

[7] Revenue generated on live weight multiplied by 5-year market average live price (USDA 5-Area Market).

[8] Revenue generated on carcass weight multiplied by 5-year market average carcass base price (USDA 5-Area Market).

[9] Calculated as: Live revenue - total cost.

[10] Calculated as: Carcass revenue - total cost.

CHAPTER IV

Effect of extended days on feed on carcass gain, efficiency, quality, and profitability for steers[1].

R. G. Bondurant*, J. C. MacDonald, PAS*, G. E. Erickson, PAS*, K. R. Brooks[†], K. W. Bruns[‡], and R. N. Funston, PAS[‡].

[*]Department of Animal Science, University of Nebraska, Lincoln, NE 68583

[†]Department of Agricultural Economics, University of Nebraska, Lincoln, NE 68583

[‡]West Central Research and Extension Center, University of Nebraska, North Platter, NE 69101

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ABSTRACT

Crossbred steers (n = 114, initial BW = 334; SD = 30 kg) were serially harvested to evaluate the change in carcass composition throughout the feeding period and profitability by feeding cattle 22 or 44 d longer than the industry average of 1.3 cm for 12th rib fat thickness. Steers were fed a common finishing diet using the GrowSafe system, allowing for calculation of individual DMI and individual steer to serve as the experimental unit. Carcass ultrasound measurements were collected on 76 steers at 1, 78, and 134 days on feed (**DOF**). Steers within the first serial group were harvested when 12th rib fat thickness was estimated to be 1.3 cm (142 DOF). The second and third groups were harvested at 163 or 185 DOF, respectively. Five-yr average market prices were applied to live animal performance and carcass characteristics to determine profitability of feeding increased DOF. Steer DMI was not different ($P \geq 0.31$ for linear and quadratic contrasts) while live ADG and live G:F decreased linearly ($P \leq 0.04$) as DOF increased. Hot carcass weight increased linearly ($P < 0.01$) from 374 (142 DOF) to 410 kg (185 DOF). Steer LM area quadratically increased ($P = 0.04$) to 163 DOF and remained constant to 185 DOF. Marbling score was not different ($P = 0.14$) while calculated YG and 12th rib fat thickness increased linearly ($P < 0.01$) as DOF increased. Total feedlot costs linearly increased ($P < 0.01$) while profitability per steer was not different ($P = 0.86$) among DOF. Under the assumed market conditions, all cattle lost money; however, 185 DOF steers minimized losses despite the added total feedlot costs due to increased HCW sold. When comparing profitability with these market conditions,

steers can be fed for 44 days longer to minimize loss even though HCW and YG discounts increase.

Key Words: carcass traits, feeding duration, profitability

INTRODUCTION

As the United States fed beef cattle markets increased in 2014 and reached record high prices in 2015, feedlot operators increased average days on feed (**DOF**) in an attempt to capture additional revenue from carcass weight. Many researchers have evaluated the idea of optimal marketing endpoint for beef cattle based on live and carcass-based performance coupled with market conditions (Pyatt et al., 2005b; Streeter et al., 2012; Tatum et al., 2012; Wilken et al., 2015). Optimal market endpoint can be described as the inflection point at which cost of additional gain equals the price received for that additional gain. As the industry moves toward more cattle marketed on a carcass-basis rather than live basis, more consideration must be given to those factors which affect optimal market endpoint. In past research, HCW has been determined as the leading factor influencing profitability (Langmeier et al., 1992; Pyatt et al., 2005a,b; Walter and Hale, 2011; Streeter et al., 2012; Tatum et al., 2012; Wilken et al., 2015). Hot carcass weight can be altered greatly by DOF. As DOF increase, HCW transfer from live ADG can be as high as 88.6% (Walter and Hale, 2011; Streeter et al., 2012). However, as cattle increase HCW, the risk for receiving discounts for overweight carcasses and USDA yield grade (**YG**) also increase (Pyatt et al., 2005b; Streeter et al., 2012) if sold on a grid. There is also an increased opportunity to capture a premium for higher USDA quality grade (**QG**) as cattle fatten, assuming an increase in marbling score (Pyatt et al., 2005b;

Streeter et al., 2012; Tatum et al., 2012). Since the energy deposited as fat on the carcass remains with the animal through harvest (minus drop weight of hide, head, hooves, and offal), this weight in fat is transferred to HCW and adds value to the animal (Streeter et al., 2012). If HCW revenue, the major driving force of price received by the producer, along with QG premiums can outweigh YG and HCW discounts, the calf may remain profitable past the live optimal marketing point.

The objective of this experiment was to determine the effect of increased DOF on profitability when steers are marketed utilizing either a live-, carcass-, or grid-based strategy and to determine when feeding increased DOF was most or least desirable based on historic pricing scenarios. The changes in carcass composition for lean protein and fat deposition over the feeding period were evaluated utilizing real-time carcass ultrasound techniques by measuring LM area, 12^{th} rib fat thickness, and intramuscular fat percent (**IMF**).

MATERIALS AND METHODS

All animal care and management procedures were approved by the University of Nebraska-Lincoln Institutional Animal Care and Use Committee (IACUC # 823).

A study was conducted at the West Central Research and Extension Center, North Platte, Nebraska. Yearling crossbred steers (n = 114, initial BW = 334; SD = 30 kg) were individually fed using a GrowSafe feeding system (GrowSafe Systems Ltd., Airdrie, AB, Canada) in an experiment to evaluate the change in carcass composition throughout the feeding period and the economic profit/loss realized by feeding cattle 22 or 44 d longer than the live industry average fat endpoint of 1.27 cm. Steers were limit-fed a diet (DM basis) containing 55% Sweet Bran (Cargill Corn Milling; Blair, NE) and 45% prairie hay for 5 consecutive d, with a 2 d BW collected to minimize variation due to gut fill (Watson et al., 2013). On the second d, steers were implanted with 200 mg trenbolone acetate, 20 mg estradiol (Revalor-200; Merck Animal Health, Madison, NJ), stratified by BW and assigned randomly to 1 of 3 pens. Steers were adapted to a concentrate finishing diet for 24 d and moved into GrowSafe feeding facility to allow for individual DMI determination.

Upon entry in the GrowSafe feeding facility, steers were weighed for 2 consecutive d with a 4% shrink applied because steers were not consuming a limit-fed diet. The average shrunk BW was not utilized as initial BW of the trial due to variations in weight caused by gut fill (Watson et al., 2013). Rather, the average BW gain (37 kg) of 114 steers for the 24-d adaptation period was added to the initial limit-fed weight. The limit-fed weight plus the 37 kg served as initial BW at the time steers entered the GrowSafe feeding system, which was considered d 1 of the trial. This method of calculating initial BW was necessary because individual DMI data could not be collected before and until steers were placed in GrowSafe system. Therefore, the 24-d adaptation period was not included in DOF calculation. Steers within pen were assigned randomly to 3 serial harvest groups, allowing for 38 steers per harvest (1/3 of each pen). Steers were not blocked by initial BW in an attempt to simulate variation within pen, as might be observed in a commercial setting. To maintain *ad libitum* intake, steers were fed twice daily a common finishing diet. The finishing ration contained 48% dry-rolled corn, 40% Sweet Bran, 7% prairie hay, and 5% supplement (DM basis) and was loaded, mixed and delivered via feed truck (Roto-mix, Dodge City, KS). The supplement contained a trace mineral and vitamins package and was also formulated to provide minimum of 13.5% CP, Ca:P of 2:1, 450 mg monensin (Rumensin 90, Elanco Animal Health, Indianapolis, IN), and 90 mg tylosin (Tylan, Elanco Animal Health) per steer daily. The vitamin and trace mineral premix was formulated to provide 1,500 IU of vitamin A, 3,000 IU of vitamin D, 3.7 IU of vitamin E per g daily, and 10% Mg, 6% Zn, 4.5% Fe, 2% Mn, 0.5% Cu, 0.3% I, and 0.05% Co daily (diet DM). At 80 DOF of the trial, steers were re-implanted with 200 mg trenbolone acetate, 20 mg estradiol (Revalor-200; Merck Animal Health) which equated to 102 d after initial implant.

Real time carcass ultrasound measurements including LM area, 12th rib fat thickness, and IMF were collected on 76 steers at 1, 78, and 134 DOF by a Centralized Ultrasound Processing (CUP Lab; Ames, Iowa) certified field technician. Images were captured using an Aloka 500-V unit (Corormetrics Medical Systems, Wallingford, CT) equipped with a 3.5-MHz, 17.2 cm linear array transducer. All images were captured on the right side of each steer. To capture 12th rib fat thickness and LM area, the steer was palpated to locate the 13th rib and the transducer was placed laterally between the 12th and 13th ribs utilizing a standoff guide to capture the image. Images for IMF prediction were collected by placing the transducer three-fourths the distance from the medial end of the LM area to the lateral end and horizontally over the 12th and 13th ribs. Ultrasound image interpretation was conducted by a certified technician at The CUP Lab. After interpretation, ultrasound IMF was converted to USDA marbling score utilizing data presented by Wilson et al. (1999a) to allow for comparisons with carcass data post-harvest.

Steers were considered to be industry average when the group was visually estimated to have 1.27 cm 12th rib fat thickness. The first set of calves was harvested at 142 DOF, while the second and third groups were harvested at 163 and 185 DOF, respectively. Total DOF for each group was calculated as total days that feed was delivered to the bunk. Carcass data were collected by Tyson Fresh Meats (Lexington, Nebraska) utilizing camera data.

Because data suggest that dressing percent increases with increasing DOF, a common dress was not applied to harvest groups for carcass adjusted live performance. Instead, the actual dressing percent calculated for each respective group was utilized to adjust carcass to live animal performance. Due to inability to collect a live weight on individual steer before harvest, the average dressing percent for each harvest group was calculated using the total HCW sold divided by the gross live weight (no shrink) of the 38 steers harvested for that day. The gross live weight was collected upon arrival at the commercial abattoir. Incremental carcass-based gain and G:F were calculated in an attempt to quantify performance over extended DOF on a carcass-basis using different sets of steers. Carcass-based gain and G:F were calculated using the following equations:

Carcass ADG for 163 DOF: (163 DOF average HCW - 142 DOF average HCW)/22 DOF

Carcass ADG for 185 DOF: (185 DOF average HCW - 163 DOF average HCW)/23 DOF

Carcass G:F for 163 DOF: 163 DOF carcass ADG / (average DM intake from 142 – 163)

Carcass G:F for 185 DOF: 185 DOF carcass ADG / (average DM intake from 163 – 185)

Economic Analyses

An economic analysis was conducted utilizing animal performance and carcass characteristics to determine total revenue generated and profitability when marketing steers at each DOF based on 5-year average market conditions (Table 1). An average of 2012 through 2016 calendar years was utilized for each item in the analysis. Economic prices of importance included Nebraska feeder steer, dietary feedstuffs including corn grain and hay, Nebraska market average dressed steer, and 5-Area (TX/OK/NM, KS, NE, CO, IA/MN) market average premiums and discounts applied to the carcass including HCW, QG, and YG. Total ration cost, yardage, veterinary/chute/misc charge, death loss, trucking and interest on both cattle and feed were also included in the analysis. All market and commodity prices were retrieved from the Livestock Marketing Information Center (Lakewood, CO) which summarizes data generated by USDA market reports.

The average monthly price received for corn, feeder and dressed steers were graphed to evaluate market conditions from January 2012 through December 2016 (Figure 6). Because corn price and ultimately ration cost influence cost of gain and profitability (Albright et al., 1993; Langmeier et al., 1992; Pyatt et al., 2005b; Tatum et al., 2012), market scenarios within the 5-year timeframe in which corn price was at its highest (August 2012) and lowest (December 2016) were evaluated within the context of the steer performance data. Market conditions within the 5-year duration in which feeder steer price and dressed carcass price were inverted (June 2015) were also evaluated using the performance data due to their influence on profitability (Walter and Hale, 2011; Streeter et al., 2012).

Statistical Analyses

All performance and carcass characteristic data were analyzed using the GLIMMIX procedure of SAS (SAS Institute, Inc., Cary, N.C.) where steer was the experimental unit and pen was included as a random effect. Covariate regression was utilized on the two pens of ultrasounded steers to develop 12th rib fat thickness, marbling score, and LM area data points. The model evaluated the effect of DOF for each variable. Orthogonal contrasts were used to test linear and quadratic effects of DOF for steers. Data for YG and QG were categorically analyzed using the GLIMMIX procedure of SAS where pen was included as a random effect, steer was the experimental unit, and the effect of DOF was determined.

RESULTS AND DISCUSSION

Animal Performance and Carcass Characteristics

Average dressing percent at harvest was 63.5, 64.6, and 64.8% for 142, 163, and 185 DOF, respectively. This would be consistent with equations derived by Bruns et al. (2004) and Wilken et al. (2015) where dressing percent increases as HCW increases. Carcass adjusted final live weight increased linearly (P < 0.01) from 576 (142 DOF) to 620 kg (185 DOF) as steers were fed an additional 44 DOF (Table 2). This equates to a daily live BW gain of 1 kg/d at the end of the finishing period. The current study ADG is similar to large pen data reported by Streeter et al. (2012) where steers gained 1.11 kg/d in the last 42 DOF. Live ADG tended to decrease linearly (P = 0.06) from 1.68 to 1.54 kg/d in the current study while G:F decreased linearly (P < 0.01) from 0.164 to 0.147

kg/kg as steers were fed to 142 or 185 DOF, respectively. The concept that live ADG and G:F decreases as DOF increases is not new. Hicks et al. (1987), Pyatt et al. (2005b), Streeter et al. (2012), and Wilken et al. (2015) described linear decreases in live ADG and G:F across DOF. In the current study, steer DMI was not different ($P = 0.59$) among DOF. Streeter et al. (2012) reported similar findings for large pen studies where increased DOF had no impact on DMI. However, this is contrary to DMI described in previous literature (Hicks et al., 1987; Pyatt et al., 2005b; Wilken et al., 2015) who reported linear increases in DMI as DOF increased and cattle became heavier. Variations in DMI within the literature could be due to time of year cattle are nearing market endpoint and the effects environment may have on intake. However, DMI is an important performance characteristic because it affects incremental cost of gain and determines optimal market endpoint. Pyatt et al. (2005b) described DMI as explaining 3% of the variation in profit among steers due to cost of gain.

As steers were fed from 142 to 185 DOF, HCW increased linearly ($P < 0.01$) from 374 (142 DOF) to 388 kg (163 DOF) and 410 kg (185 DOF). This is an increase of 14 kg for the first 21 d and a 22 kg increase in HCW for the next 22 d. These results are in agreement with Streeter et al. (2012) in which steers increased HCW by 17 kg and 20 kg for each incremental increase of 21 DOF. In the current study, incremental carcass ADG was 0.64 kg between days 142 and 163, and 0.97 kg between days 163 and 185. Carcass G:F was 0.065 between 142 and 163 days, and 0.092 between 163 and 185 days describing an increasing rate of HCW gain as DOF increases. Streeter et al. (2012) reported a slightly higher rate of HCW ADG at 0.95 kg/d for steers while Wilken et al.

(2015), utilizing regression of pooled data, described HCW gain as increasing at a decreasing quadratic rate as DOF increased and May et al. (1992) reported HCW increasing linearly as DOF was increased.

Steer LM area quadratically increased (P = 0.04) from 89.0 to 93.5 cm^2 (142 and 163 DOF, respectively) and decreased slightly to 92.3 cm^2 for 185 DOF. Data from other studies report linear increases in LM area as HCW increased, however LM area as a percentage of HCW gain decreased with increasing DOF (Hicks et al., 1987; May et al., 1992; Bruns et al., 2004; Streeter et al., 2012). Carcass marbling score numerically increased from 475 to 506 (142 and 185 DOF, respectively) but was not significantly different (P = 0.14) among treatments. Although the increase in marbling score was not significant, one would expect for marbling score to increase as cattle fatten with increased DOF. However, similar to the current study, Brandt et al. (1992) and Haugen et al. (2004) reported that DOF had no effect on marbling score. Others have described a linear increase in marbling score (Bruns et al., 2004; Pyatt et al., 2005b) or a quadratic increase in marbling score (May et al., 1992) as DOF increase. Although there was a numeric increase in steers with higher QG as DOF increased to 185 (Fig. 1), there was no difference in QG among DOF (P = 0.18). For the 142 DOF steers, 84.2% graded Choice (400 = $Small^{00}$) or better while 76.3% graded Choice or better for the 163 d steers. The 185 d steers numerically had the greatest number of steers grading Choice or better at 86.8% while also having an increased percentage of steers grading upper 2/3 Choice. Even though marbling score did not statistically increase among DOF ($P \geq 0.14$), carcass 12^{th} rib fat thickness increased linearly (P < 0.01) from 1.24 to 1.75 cm as DOF increased from 142 to 185. Similar results were reported by May et al. (1992) and Van Koevering et al. (1995) describing linear increases while Hicks et al. (1987) and Bruns et al. (2004) described quadratic increases in 12^{th} rib fat thickness as DOF increased. Bruns et al. (2004) attributed the difference between the linear and quadratic response to DOF to a point of inflection for 12^{th} rib fat thickness rate of gain in which a plateau was reached when a quadratic response was noted. As steers in the present study fattened with increased DOF, calculated YG linearly increased ($P < 0.01$) from 2.89 to 3.56 when steers were fed 142 and 185 DOF. The increase in DOF had an effect on the percentage of steers with final YG 1 through 5 (Fig. 2; $P < 0.01$). Steers harvested at 185 DOF had 10.5% more YG 3 than both 142 and 163 DOF which were not different. The percentage steers within harvest group with final YG 4 increased from 2.6, to 10.5 and 31.6% as DOF increased from 142 to 163 and 185, respectively. However, there were no steers harvested on 185 d with YG 5 while 2.6% had YG 5 for 142 and 163 DOF. If steers had been fed another 21 d, it is logical to assume that increases in YG 5 would have been observed. It has been well documented that YG increases linearly as DOF increases (Haugen et al., 2004; Pyatt et al., 2005b; Van Koevering et al., 2005; Streeter et al. 2012). When marketing on a grid basis, percent YG 4 and 5 becomes a significant factor when determining optimal market endpoint in order to minimize YG discounts while increasing revenue generated from HCW (Tatum et al., 2012).

Ultrasound Performance

On d 1 when initial ultrasound was conducted, 12^{th} rib fat thickness, IMF converted to marbling score, and LM area were not different ($P \geq 0.42$) among harvest groups. Steer 12th rib fat thickness increased quadratically (P < 0.01) from 0.48 cm on d 1 to 1.65 cm on d 185 (Fig. 3). Steers ultrasounded at 134 DOF had 1.19 cm rib fat, while those harvested at 142 DOF had a carcass 12th rib fat thickness of 1.12 cm. This small discrepancy in fat thickness may be due to hide pulling and carcass trim at the commercial abattoir or the inherent differences in ultrasound and camera measurements. May et al. (1992) and Bruns et al. (2004) also described quadratic increases in 12th rib fat thickness. Marbling score increased quadratically (P < 0.01) from 346 at d 1 (initial ultrasound) to 523 at 185 DOF (Fig. 4). The quadratic trend for marbling score is consistent with data described by May et al. (1992). Measured LM area increased quadratically (P < 0.01) from 66.5 cm^2 (initial ultrasound) on d 1 to 92.9 cm^2 as steers were fed to 185 DOF (Fig. 5). Others have reported on the quadratic effects of DOF on LM area as well (Hicks et al., 1987; May et al., 1992; Bruns et al., 2004; Streeter et al., 2012) in which the calf increases linearly to physiological maturity and then the rate of LM area gain begins to increase at a decreasing rate.

Economic Analyses

Several market scenarios were evaluated based on corn, feeder, and dressed steer prices received and applying them to individual steer performance and carcass characteristics. A 5-yr average from January 2012 through December 2016 was evaluated and graphed in Fig. 6. Utilizing the average monthly prices for those 5 yr, three additional timepoints were evaluated based on corn price and the relationship between feeder and dressed steer prices. The monthly averages for August 2012 were utilized because corn was greatest at $7.63/25.4 kg ($/as-is bushel). June 2015 monthly average prices were also analyzed utilizing the steer data because feeder to dressed steer price was inverted during this time. Finally, December 2016 average prices were evaluated within the context of the performance data because corn price averaged \$3.33/25.4 kg (\$/as-is bushel) and the feeder to dressed steer price was indicative of average market relationships. Based on the average prices for feedstuffs (including corn and hay), feeder price (45.5 kg increments), dressed steer price, and premiums and discounts for overweight carcasses, YG and QG were applied for each of the respective market timepoints.

5-year Average Market Analyses

The 5-yr average market prices are described in Table 1. Corn averaged \$4.83/25.4 kg (\$/bushel) which equated to a ration cost of \$202.40/908 kg DM (\$/ton). Average feeder calf price for a 318 to 363 kg calf was \$178.11/45.4 kg (\$/100 lb.) and varied based on 45.4 kg (100 lb.) slides. Average base Choice dressed steer price was \$212.57/45.4 kg. The 5-yr weighted average premiums for QG and YG 1.0 – 2.9 and discounts for HCW and YG 4.0 – 5.0 were applied to the carcass characteristics of each steer. Additionally, strategies for marketing steers on a live- and carcass-basis were evaluated within the context of the 5-yr averages to compare to grid-based marketing. The 5-yr average live price for finished steers was \$134.14/45.4 kg.

The purchase cost was not different ($P = 0.36$) among DOF (Table 3). As DOF increased from 142 to 185, feed cost linearly increased from \$343.23 to \$450.63 per steer, respectively ($P < 0.01$). Total feedlot costs including feed increased linearly ($P < 0.01$) with increasing DOF (\$495.93, \$555.62 and \$634.61 for 142, 163, and 185 d, respectively). There was a tendency ($P = 0.08$) for HCW discounts to linearly increase from \$0.71 to \$1.16 and \$10.48 per steer as DOF increased from 142 to 163 and 185, respectively. Although steers within DOF treatments graded at least 80% Choice, the few cattle within each group which did not grade Choice brought average discounts of \$6.00 (142 DOF), \$17.27 (163 DOF), and \$6.09 (185 DOF) per steer but were not different among DOF ($P \geq 0.20$). This discount as DOF increased is counter-intuitive to what would be expected as cattle reach maturity and fatten. There was a linear increase ($P < 0.01$) in YG discounts as steers were fed increasing DOF. Steers fed to 142 d had a YG premium of \$6.54 per steer while those fed 163 DOF had a \$0.49 discount and 185 DOF received an average discount of \$21.67 per steer. These discounts illustrate the importance of selecting for high quality cattle (cattle with increased rates of intramuscular fat deposition) when marketing on a grid basis because an increase in QG to receive a premium can offset added discount as YG 4 and 5 increase. In this scenario (5-yr average), QG discounts accounted for nearly 50% of the total discounts received across all treatments.

When evaluating revenue generated from each of the marketing strategies, all three linearly increased ($P < 0.01$) in revenue as DOF increased from 142 to 185. This increase in revenue is driven by the increase in final BW (live-based marketing) and HCW (carcass- and grid-based marketing). Overall, carcass-based marketed steers had greater revenue compared to live- and grid-based across DOF because HCW value was maximized with no discounts applied compared to grid-based marketing. Even though revenue increased linearly for all marketing strategies, all serial groups within strategy lost money due to 5-yr average market conditions. Steers marketed on a live-basis lost the greatest amount at an average of $398.81 (142 DOF), $417.50 (163 DOF), and $394.07 (185 DOF) loss per steer but were not different ($P \geq 0.36$). Contrary to live, carcass-based marketed steers had a slight tendency ($P = 0.11$) to linearly minimize loss per steer as DOF increased from 142 ($386.80) to 185 DOF ($343.28). For those steers marketed on a grid-basis and fed to 142 d, loss per steer equated to $386.86 while those fed 163 DOF had a loss of $394.76 and the 185 d steers minimized loss at $381.62 per steer but were not different ($P \geq 0.68$).

Steers fed for 163 and 185 DOF sold 14 and 36 kg of additional HCW compared to the 142 DOF which equated to an additional revenue of $66.51 and $169.46 per steer, respectively (Table 4). The incremental cost of HCW gain was calculated by dividing the total additional feedlot costs for 22 d by the increase in HCW. Cost of HCW gain decreased from $4.26 to $3.59 per kg as steers were fed an additional 22 d (142 to 163 and 163 to 185 DOF, respectively). The decrease in HCW cost of gain is contrary to live cost of gain during the end of the feeding period, as live cost of gain is increasing. The HCW cost of gain decreased during this time because carcass weight is continuing to increase.

August 2012 Average Market Analyses – High Corn Price

During August 2012 (Table 5), corn reached its highest for the 5-year average at $7.63/25.4 kg ($/as-is bushel) which equated to a ration cost of $303.43/908 kg DM ($/ton). Average feeder calf price for a 318 to 363 kg calf was less than that of the 5-year average at $147.07/45.4 kg ($/100 lb.). The average base Choice dressed steer price was also less than the 5-year average at $187.62/45.4 kg. The weighted average during August 2012 for QG and YG 1.0 – 2.9 premiums, and discounts for HCW and YG 4.0 – 5.0 were applied to the carcass characteristics of each steer.

Similar to the 5-year average, initial steer cost was not different (P = 0.68) among DOF (Table 5). Feed cost and total feedlot costs increased linearly with increasing DOF ($P < 0.01$). Because corn was priced high during this month (August 2012), feed costs accounted for 79.5, 79.9, and 80.7% of total feedlot costs as DOF increased from 142 to 163 and 185, respectively. Pyatt et al. (2005c) described that HCW and QG importance tended to decrease in terms of profitability as the ration price increased. Within this scenario, HCW discounts were greater than the 5-year average due to a discount of $22.03/45.4 kg received for HCW ≥ 409 kg. The discounts per steer for HCW linearly increased ($P < 0.01$) as DOF increased ($11.92, 142 DOF; $59.54, 163 DOF; $101.43, 185 DOF). Although the QG discounts per steer varied, DOF had no impact ($P \geq 0.27$). Steers fed to 142 DOF had an average YG premium of $3.92 per steer while 163 and 185 d steers received discounts of $3.75 and $25.59, respectively ($P < 0.01$).

Because base dressed steer price was $24.95/45.4 kg less than the 5-year average, revenue generated from HCW was decreased to $1543.73 for 142 DOF, $1602.44 for 163 DOF, and $1693.31 for 185 DOF (linear, $P < 0.01$). Total revenue was not different ($P \geq$ 0.22) among treatments ($1532.62, 142 DOF; $1526.06, 163 DOF; $1563.07, 185 DOF). Due to increased HCW discounts under these market conditions, profitability was lower as DOF increased (linear, $P < 0.01$). While 142 d steers averaged a loss of $198.10, the steers fed to 163 and 185 DOF lost $282.67 and $351.96 per steer, respectively. The increase in ration cost due to increased corn price, coupled with the increase in HCW discounts during August 2012, illustrates market conditions when feeding cattle to longer DOF would not prove more profitable compared to selling at normal DOF.

June 2015 Average Market Analyses – Inverted Feeder to Dressed Price

During June 2015 (Table 6), corn, \$3.59/25.4 kg (\$/bushel), was significantly lower than the August 2012 analysis, which equated to a decreased ration cost of \$157.04/908 kg DM (\$/ton). Average feeder calf price for a 318 to 363 kg calf was at a record high \$242.83/45.4 kg (\$/100 lb.) which is a \$95.76/45.4 kg increase compared with the August 2012 analysis. The average base Choice dressed steer price (\$241.01/45.4 kg) was less than the average feeder price for the month. The weighted average during June 2015 for QG and YG 1.0 – 2.9 premiums, and discounts for HCW and YG 4.0 – 5.0 were applied to the carcass characteristics of each steer.

Due to the increased feeder price for June 2015, initial purchase price averaged \$1807.21 per steer across treatments. Initial purchase cost was not different among DOF ($P \geq 0.44$). As DOF increased, feed cost and total feedlot costs increased linearly ($P < 0.01$). Under these market conditions feed cost accounted for 62.6, 63.3, and 64.7% of total feedlot costs (142, 163, and 185 DOF, respectively). Discounts received for HCW tended (linear, $P = 0.09$) to increase from \$0.68 (142 DOF) to \$1.10 (163 DOF) and \$10.40 (185 DOF) per steer. Quality grade discounts averaged \$6.14 for 142 DOF, \$16.86 for 163 DOF, and \$6.26 for 185 DOF but were not different among treatments ($P \geq 0.18$). Similar to other analyses, 142 d steers received an average YG premium of \$6.23 per steer while steers fed 163 and 185 d received discounts of \$0.07 and \$19.25 per steer, respectively (linear, $P < 0.01$). As the price received for dressed steers increased, the importance of HCW increased and the value of QG decreased (Pyatt et al., 2005c).

As DOF increased, revenue generated from HCW and total revenue per steer increased (linear, $P < 0.01$). Hot carcass weight revenue equated to $1983.02, $2058.43, and $2175.16 per steer while total revenue generated was $1982.53, $2040.31, and $2139.16 per steer (142, 163, and 185 DOF, respectively). Although all treatments lost money under these market conditions due to increased initial feeder price, increasing DOF for steers tended to minimize loss ($P = 0.08$). Steers fed to 163 DOF decreased losses by $11.45 per steer while those fed to 185 d decreased losses by $54.21 per steer compared to 142 DOF. These market conditions indicate a scenario in which feeding cattle to increased DOF might not guarantee profit, but minimize losses when feeder purchase price is high.

December 2016 Average Market Analyses – Low Corn Price

During December 2016 (Table 7), corn was on the lower end of the 5-year average at $3.33/25.4 kg ($/as-is bushel). This equated to the lowest ration cost of all the scenarios at $147.65/908 kg DM ($/ton). Average feeder calf price for a 318 to 363 kg calf was $138.01/45.4 kg ($/100 lb.). The average base Choice dressed steer price was $178.36/45.4 kg. Similar to previous analyses, the weighted average during December 2016 for QG and YG 1.0 – 2.9 premiums, and discounts for HCW and YG 4.0 – 5.0 were applied to the carcass characteristics of each steer. These market conditions for December 2016 would be indicative of a profitable feeding market with decreased corn and feeder price and a moderate dressed carcass price.

Initial purchase price was not different ($P \geq 0.79$) and averaged $1020.71 among treatments. As with previous scenarios, feed cost and total feedlot costs increased linearly with increasing DOF ($P < 0.01$). However, feed cost accounted for 66.2, 66.8, and 68.0% of total feedlot costs. The HCW discounts received tended (linear, $P = 0.08$) to increase from $0.70 (142 DOF) to $1.09 (163 DOF) and $10.41 (185 DOF) per steer which are very similar discounts to the June 2015 analysis. Discounts for QG were not different among treatments ($P \geq 0.14$) and averaged $13.03 for 142 DOF, $29.63 for 163 DOF, and $13.39 for 185 DOF. Steers fed 142 and 163 DOF received an average YG premium of $9.36 and $1.77 per steer while steers fed 185 DOF received a discount $21.96 per steer, respectively (linear, $P < 0.01$). Although the discounts for HCW were similar to previous analyses, the YG premiums and discounts shifted so that only 185 DOF steers received a discount.

Revenue generated from HCW for December 2016 linearly increased ($P < 0.01$) from $1467.54 (142 DOF) to $1523.35 (163 DOF) and $1609.73 (185 DOF). The increases in HCW revenue increased total revenue by $30.95 for 163 DOF and $100.55 for 185 DOF steers compared to 142 DOF (linear, $P < 0.01$). However, profitability was not different ($P \geq 0.50$) among treatments. Under the December 2016 market conditions, steers made an average of $62.97, $49.15, and $62.10 when fed to 142, 163, and 185 DOF, respectively. Because ration price decreased under these conditions, feeding an additional 22 d past 185 DOF to capture added HCW could add revenue at a decreased cost.

Overall Economic Conclusions

The only profitable marketing scenario under the given set of cattle was when feeder price and dressed price were inverted, i.e. feeder price paid was greater than dressed carcass price received. In this scenario, feeding steers for increased DOF proved beneficial because the increased initial feeder cost can be dispersed over increased carcass weight sold. This can equate to additional profit or minimizing losses sustained dependent on market conditions. Contrary to Wilken et al. (2015) who concluded that feeding cattle increased DOF increased profitability as corn price increased, the August 2012 (high corn price) analysis concluded that feeding steers additional DOF decreased profitability due to increased discounts. Wilken et al. (2015) assumed that QG and associated premiums would increase with increased DOF serving to offset additional discounts incurred; however, that was not the result under the current study because QG did not significantly increase. Thus, economic return was greatly reduced for steers fed increased DOF due to increased feed cost (high corn price) coupled with discounts for overweight carcasses and YG.

Figure 7 depicts the average monthly change in Choice to Select spread, USDA YG 4 discount, and the discount for HCW ≥ 477 kg (per 45.4 kg of HCW) for January 2012 to December 2016. While the discounts for YG 4 and overweight HCW have remained relatively constant during the 5-year average, the Choice to Select spread depicts the greatest variability from month to month. The spread has varied from $21.76/45.5 kg in June 2016 to as little as $1.24/45.5 kg in February 2014. Pyatt et al. (2005c) reported QG importance increased while HCW and YG importance decreased with an expanding Choice to Select spread. Many researchers have concluded that increases in QG as cattle are fed longer DOF has a positive return when marketing on a grid, however, the determining factor on feeding increased DOF is ultimately HCW and the associated discount for overweight carcasses (Fuez, 2002; Pyatt et al., 2005a; Streeter et al., 2012,; Tatum et al., 2012). Feuz (2002) and Walter and Hale (2011) concluded that increases in HCW with increased DOF can overcome the YG 4, YG 5, and overweight carcass discounts.

Consideration should be given to the fact these steers were not fed a β-agonist in the trial. Researchers have reported that β-agonists increase LM area, DP, and HCW while decreasing YG compared to a negative control (Ricks et al., 1984; Avendano-Reyes et al., 2006; Vasconcelos et al., 2008; Elam et al., 2009) by repartitioning energy to protein accretion as opposed to fat deposition. Feeding a β-agonist towards the end of the feeding period could aid in minimizing discounts for YG 4 and 5 carcasses while also adding HCW to capture additional revenue. However, increases in HCW will also increase risk for overweight carcasses as well. Additionally, β-agonists have been reported to negatively affect QG for cattle fed similar DOF (Ricks et al., 1984; Avendano-Reyes et al., 2006; Vasconcelos et al., 2008; Elam et al., 2009) which could affect possible premiums received for increases in marbling score.

IMPLICATIONS

Although carcass adjusted live ADG and G:F decreased with increasing days on feed, steer HCW increased by 14 and 36 kg with 22 or 44 additional days on feed compared to the industry average of selling at 1.27 cm rib fat. When evaluating steers fed longer days using the 5-year average, the decreased economic loss despite the added total feedlot costs can be attributed to increasing final BW for live marketing and increasing HCW revenue for carcass- and grid-based marketing. Although increases in yield grade and subsequent discounts were observed as days on feed increased, the premiums received for steers, which had higher quality grade coupled with the value of additional HCW, minimized total loss (5-year and June 2015 analyses) when marketed on a grid basis. When corn price (ration cost) is increased (August 2012), feeding steers increasing days is not economical because the incremental feed cost can not be recovered when coupled with yield grade and carcass discounts. Conversely, when corn price (ration cost) is decreased (December 2016), increasing days on feed is profitable by capturing added carcass value in HCW. When comparing profitability using varying market conditions, steers can be fed for 44 d longer than industry average of 1.27 cm rib fat to either minimize losses (5-year and June 2015) or increase profitability per steer (December 2016). If market conditions offer decreased corn price and cost-effective feeder purchase price, steers can be fed increased days on feed and sold on a grid basis to capture profit potential for increased HCW and possibly quality grade.

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Table 1. Prices used for economic analysis of steers fed increasing days on feed. Negative values denoted in ( ).

Yard and feed information,	
Daily yardage, $/steer	0.45
Veterinary/chute/misc., per steer	15.00
Death loss, %	2.0
Trucking, $/steer	5.00
Interest on feedlot charges, %	5.0
Interest on steer, %	5.0
Feedstuffs[1],	$/908 kg DM
Corn ($4.83/bushel)	204.14
Ration cost	202.40
Animal information,	
Nebraska feeder calves[2], kg	$/45.4 kg
227 – 271	210.08
272 – 317	191.65
318 – 363	178.11
364 – 408	167.92
409 – 453	160.90
454 – 499	152.22
Dressed steer, base Choice[3]	212.57
Carcass premiums and discounts grid[4],	$/45.4 kg
HCW, kg	
182 – 226	(27.27)
227 – 249	(21.97)
250 – 272	(3.15)
273 – 408	-
409 – 453	(0.22)
454 – 476	(2.34)
≥ 477	(23.26)
USDA quality grade[5],	
Prime	18.32
Choice	-
Select	(9.57)
Standard	(22.82)
USDA yield grade,	
1.00 – 1.99	4.78
2.00 – 2.49	2.44
2.50 – 2.99	2.32
3.00 – 3.49	-
3.50 – 3.99	-
4.00 – 4.99	(9.23)
≥ 5.00	(14.82)

[1] Values from the USDA 5-Area monthly feedstuffs averaged for January 2012 – December 2016.
[2] Values from the Nebraska weekly feeder market sales averaged for January 2012 – December 2016.
[3] Values from the Nebraska monthly fed market sales averaged for January 2012 – December 2016.
[4] 5-Area Market Premiums and Discounts received for dressed steers averaged for January 2012 – December 2016.
[5] 200 = Traces^{00}, Standard; 300 = Slight^{00}, Select; 400 = Small^{00}, Choice; 700 = Slightly Abundant^{00}, Prime.

Table 2. Feedlot and carcass performance of steers fed an additional 22 or 44 days on feed.

	Days on feed[2]				Contrasts[3]	
Live animal performance[1],	142	163	185	SE	Linear	Quadratic
Initial BW, kg	334	334	334	5	0.98	0.96
Final BW, kg	576	588	620	8	< 0.01	0.35
DMI, kg/d	10.8	10.7	10.9	0.2	0.59	0.31
Live ADG, kg	1.68	1.56	1.54	0.05	0.06	0.37
Live G:F, kg/kg	0.164	0.153	0.147	0.002	< 0.01	0.30
Carcass performance,						
HCW, kg	374	388	410	5	< 0.01	0.56
LM area, cm^2	89.0	93.5	92.3	1.3	0.06	0.04
Marbling score[3]	475	476	506	15	0.14	0.42
12th rib fat, cm	1.24	1.47	1.75	0.10	< 0.01	0.79
Calculated yield grade[4]	2.89	3.05	3.56	0.16	< 0.01	0.20

[1] Live animal performance calculated using carcass adjusted final live weight: HCW divided by actual dressing percent from each serial harvest time point (64.83, 65.91. and 66.14%, respectively).

[2] Steers fed to 142, 163, and 185 days on feed (n = 38 per treatment). 142 was harvested at live animal industry average rib fat depth.

[3] *P*-values for preplanned linear and quadratic contrasts.

[4] 200=Traces^{00}, 300=Slight^{00}, 400=Small^{00}, 500=modest^{00}, 600=moderate^{00}, 700=Slightly Abundant^{00}, 800=Moderately Abundant^{00}

[5] Calculated as: yield grade = 2.5 + (0.98 x 12th rib fat thickness, cm) – (0.05 x LM area, cm^2) + (0.2 x KPH, %) + (0.0084 x HCW, kg); USDA, 1997.

Table 3. Feedlot economics for steers fed increasing days on feed utilizing 5-year average market prices (average $/steer).

	Days on feed[1]				Contrasts[2]	
Inputs,	142	163	185	SEM	Linear	Quadratic
Purchase cost[3]	1639.71	1635.83	1626.92	9.91	0.36	0.83
Feed cost[4]	343.23	387.72	450.63	8.03	< 0.01	0.20
Total feedlot costs[5]	495.93	555.62	634.61	8.11	< 0.01	0.19
Grid premiums and discounts[6],						
HCW	(0.71)	(1.16)	(10.48)	3.96	0.08	0.36
Quality grade	(6.00)	(17.27)	(6.09)	7.19	0.99	0.20
Yield grade	6.54	(0.49)	(21.67)	7.90	< 0.01	0.33
Market strategy revenue,						
Live[7]	1737.02	1773.76	1867.69	25.14	< 0.01	0.35
Carcass[8]	1749.02	1815.53	1918.48	25.65	< 0.01	0.56
Grid[9]	1748.97	1796.50	1880.14	26.63	< 0.01	0.58
Market strategy profit[10],						
Live	(398.81)	(417.50)	(394.07)	18.83	0.86	0.36
Carcass	(386.80)	(375.73)	(343.28)	19.26	0.11	0.65
Grid	(386.86)	(394.76)	(381.62)	20.80	0.86	0.68

[1] Steers fed to 142, 163, and 185 days on feed (n = 38 per treatment). 142 was harvested at live animal industry average rib fat depth.

[2] *P*-values for preplanned linear and quadratic contrasts.

[3] Calculated using Nebraska feeder market sales with 45.4 kg weight groups multiplied by initial BW/45.4.

[4] Calculated by: total DM feed usage multiplied by ration cost/ton DM.

[5] Total feedlot costs including feed, vet. and misc, yardage, trucking, death loss, and interest.

[6] Values from USDA 5-Area market premiums and discounts received for dressed steers.

[7] Calculated as: (Carcass adjusted final BW/45.4) * Nebraska live steer price averaged from January 2012 – December 2016.

[8] Calculated as: (HCW/45.4) * Nebraska dressed steer price averaged from January 2012 – December 2016.

[9] Calculated as: HCW sold + premiums and discounts received per steer.

[10] Calculated as: market strategy revenue - (purchase cost + total feedlot cost).

Table 4. Comparative feedlot economics of feeding an additional 22 or 44 days utilizing 5-year average market prices ($/steer).

	Days on Feed[1]	
Item,	142 - 163	163 - 185
Added feed cost	44.49	62.91
Added total feedlot cost[2]	59.69	78.99
Additional HCW sold, kg/steer	14	22
Additional revenue from HCW	66.51	102.95
Total additional revenue[3]	47.53	83.64
Cost of HCW gain, $/kg[4]	4.26	3.59

[1] Values calculated per steer for 22 or 44 additional days on feed, respectively. n = 38 steers per treatment.

[2] Including additional feed, vet. and misc, yardage, trucking, death loss, and interest for added days on feed.

[3] Additional $/steer received including discounts and premiums.

[4] Calculated as: added total feedlot cost / additional HCW sold.

Table 5. Feedlot economics for steers fed increasing days on feed utilizing August 2012 average market prices (Averge $/steer). August 2012 incurred the highest average corn price during 5-yr average market analysis.

	Days on feed[1]				Contrasts[2]	
Inputs,	142	163	185	SE	Linear	Quadratic
Purchase cost[3]	1083.51	1081.14	1077.41	10.58	0.68	0.96
Feed cost[4]	514.55	581.25	675.56	12.04	< 0.01	0.20
Total feedlot costs[5]	646.97	727.83	837.48	12.22	< 0.01	0.19
Grid premiums and discounts[6],						
HCW	(11.92)	(59.54)	(101.43)	14.54	< 0.01	0.87
Quality grade	(3.15)	(13.06)	(3.10)	7.34	0.99	0.27
Yield grade	3.92	(3.75)	(25.59)	9.27	< 0.01	0.38
Outputs,						
HCW sold[7]	1543.73	1602.44	1693.31	22.64	< 0.01	0.56
Grid-based revenue[8]	1532.62	1526.06	1563.07	18.06	0.22	0.30
Grid-based profit[9]	(198.10)	(282.67)	(351.96)	17.84	< 0.01	0.69

[1] Steers fed to 142, 163, and 185 days on feed (n = 38 per treatment). 142 was harvested at live animal industry average rib fat depth.

[2] *P*-values for preplanned linear and quadratic contrasts.

[3] Calculated using Nebraska feeder market sales with 45.4 kg weight groups multiplied by initial BW/45.4.

[4] Calculated by: total DM feed usage multiplied by ration cost/ton DM.

[5] Total feedlot costs including feed, vet. and misc, yardage, trucking, death loss, and interest.

[6] Values from USDA 5-Area market premiums and discounts received for dressed steers.

[7] Calculated as: (HCW/45.4) * Nebraska dressed steer price averaged for August 2012.

[8] Calculated as: HCW sold + premiums and discounts received per steer.

[9] Calculated as: grid-based revenue - (purchase cost + total feedlot cost).

Table 6. Feedlot economics for steers fed increasing days on feed utilizing June 2015 average market prices (Average $/steer). During June 2015, feeder price was greater than dressed steer price (inverted).

	Days on feed[1]				Contrasts[2]	
Inputs,	142	163	185	SE	Linear	Quadratic
Purchase cost[3]	1812.58	1809.18	1799.87	11.76	0.44	0.84
Feed cost[4]	266.31	300.83	349.64	6.23	< 0.01	0.20
Total feedlot costs[5]	425.09	475.09	540.19	6.31	< 0.01	0.20
Grid premiums and discounts[6],						
HCW	(0.68)	(1.10)	(10.40)	4.00	0.09	0.36
Quality grade	(6.14)	(16.86)	(6.26)	6.51	0.99	0.18
Yield grade	6.23	(0.07)	(19.25)	7.10	< 0.01	0.33
Outputs,						
HCW sold[7]	1983.02	2058.43	2175.16	29.08	< 0.01	0.56
Grid-based revenue[8]	1982.53	2040.31	2139.16	29.55	< 0.01	0.57
Grid-based profit[9]	(255.28)	(243.83)	(201.07)	22.15	0.08	0.56

[1] Steers fed to 142, 163, and 185 days on feed (n = 38 per treatment). 142 was harvested at live animal industry average rib fat depth.
[2] *P*-values for preplanned linear and quadratic contrasts.
[3] Calculated using Nebraska feeder market sales with 45.4 kg weight groups multiplied by initial BW/45.4.
[4] Calculated by: total DM feed usage multiplied by ration cost/ton DM.
[5] Total feedlot costs including feed, vet. and misc, yardage, trucking, death loss, and interest.
[6] Values from USDA 5-Area market premiums and discounts received for dressed steers.
[7] Calculated as: (HCW/45.4) * Nebraska dressed steer price averaged for June 2015.
[8] Calculated as: HCW sold + premiums and discounts received per steer.
[9] Calculated as: grid-based revenue - (purchase cost + total feedlot cost).

Table 7. Feedlot economics for steers fed increasing days on feed utilizing December 2016 average market prices (Average $/steer). December 2016 incurred the lowest average corn price during 5-yr average market analysis.

	Days on feed[1]				Contrasts[2]	
Inputs,	142	163	185	SE	Linear	Quadratic
Purchase cost[3]	1022.34	1021.72	1018.08	11.61	0.79	0.91
Feed cost[4]	250.37	282.83	328.72	5.86	< 0.01	0.20
Total feedlot costs[5]	377.82	423.56	483.55	5.99	< 0.01	0.20
Grid premiums and discounts[6],						
HCW	(0.70)	(1.09)	(10.41)	3.96	0.08	0.35
Quality grade	(13.03)	(29.63)	(13.39)	9.04	0.98	0.14
Yield grade	9.36	1.77	(21.96)	8.57	< 0.01	0.31
Outputs,						
HCW sold[7]	1467.54	1523.35	1609.73	21.52	< 0.01	0.56
Grid-based revenue[8]	1463.31	1494.26	1563.86	23.95	< 0.01	0.51
Grid-based profit[9]	62.97	49.15	62.10	16.84	0.97	0.50

[1] Steers fed to 142, 163, and 185 days on feed (n = 38 per treatment). 142 was harvested at live animal industry average rib fat depth.
[2] *P*-values for preplanned linear and quadratic contrasts.
[3] Calculated using Nebraska feeder market sales with 45.4 kg weight groups multiplied by initial BW/45.4.
[4] Calculated by: total DM feed usage multiplied by ration cost/ton DM.
[5] Total feedlot costs including feed, vet. and misc, yardage, trucking, death loss, and interest.
[6] Values from USDA 5-Area market premiums and discounts received for dressed steers.
[7] Calculated as: (HCW/45.4) * Nebraska dressed steer price averaged for December 2016.
[8] Calculated as: HCW sold + premiums and discounts received per steer.
[9] Calculated as: grid-based revenue - (purchase cost + total feedlot cost).

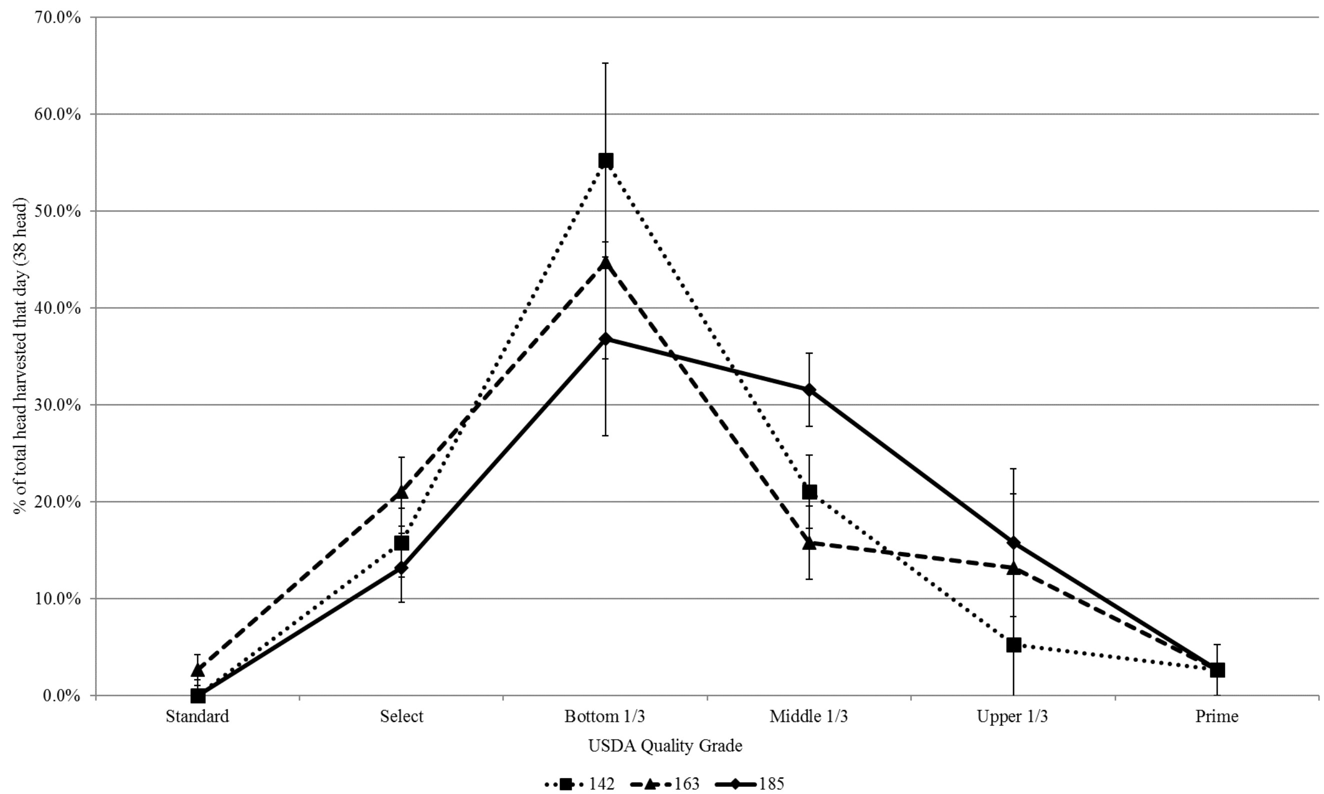

Figure 1. Percent of total steers harvested (38 steers/d) on days 142 (dotted line), 163 (dashed line), and 185 (solid line) having USDA quality grade of Standard, Select, bottom 1/3 Choice, middle 1/3 Choice, upper 1/3 Choice, and Prime. Although there was an increase in the percentage of steers grading upper 2/3 Choice for 185 d, there was no difference in USDA quality grade (P = 0.18) as steers were fed increasing days on feed.

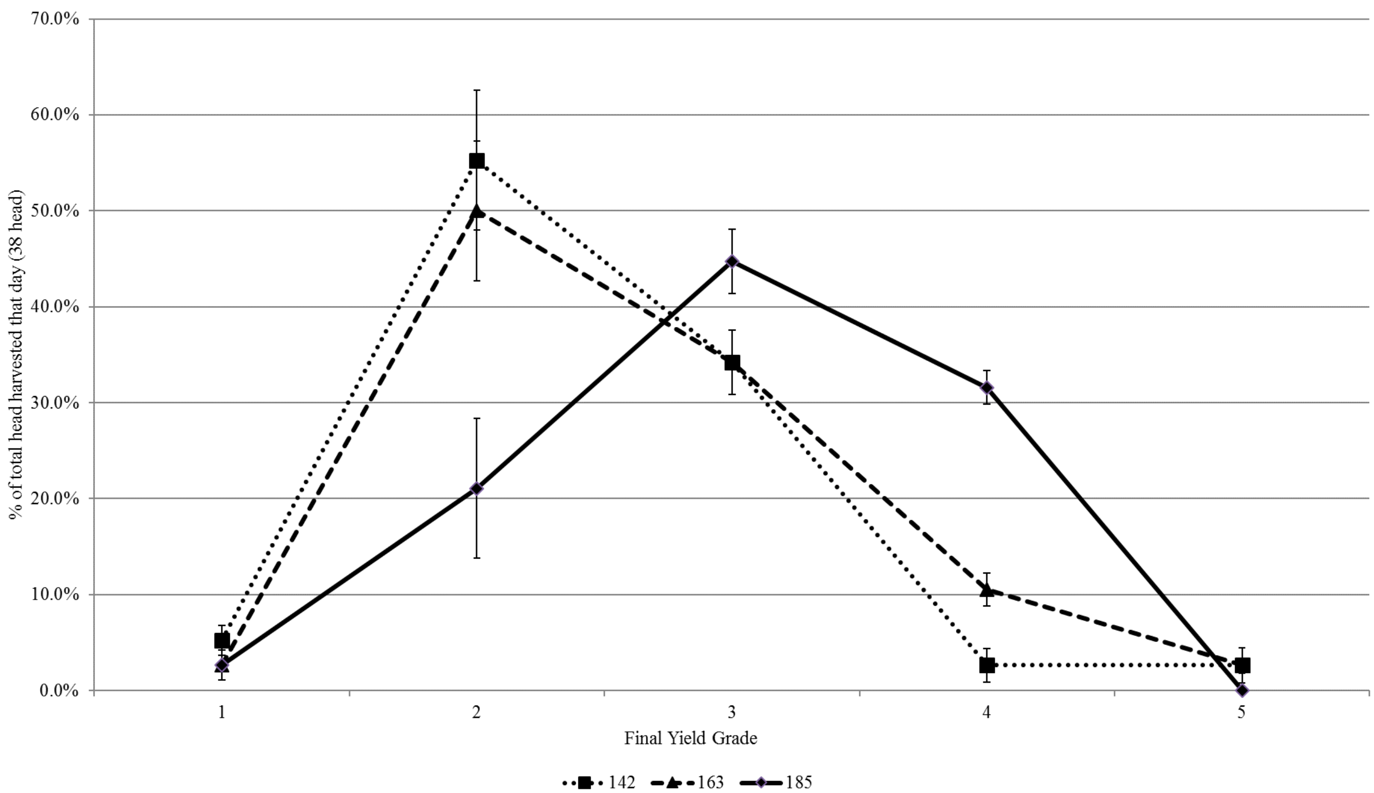

Figure 2. Percent of total steers harvested (38/d) on days 142 (dotted line), 163 (dashed line), and 185 (solid line) with final YG 1 through 5. Final YG was increased ($P < 0.01$) with increasing days on feed from 142 to 185 where steers fed 185 DOF had the greatest percent YG 3 and 4.

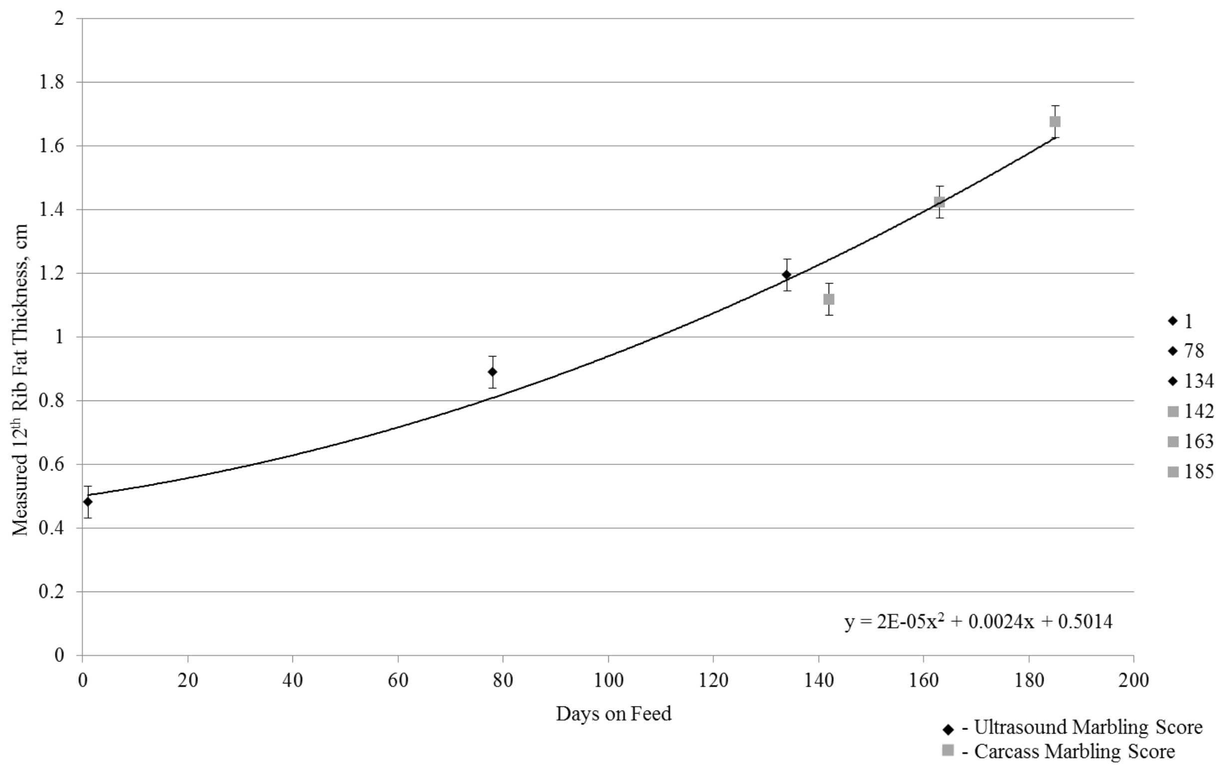

Figure 3. Measured 12th rib fat thickness (cm) throughout days on feed. Days 1, 78, and 134 were measured using real-time carcass ultrasound on 2 pens of cattle (n = 76) and averaged. Days 142, 163, and 185 were measured at time of harvest for each serial slaughter group (38 steers) and averaged. Steer 12th rib fat increased quadratically ($P < 0.01$) from 0.48 cm at d 1 to 1.75 cm at 185 days on feed.

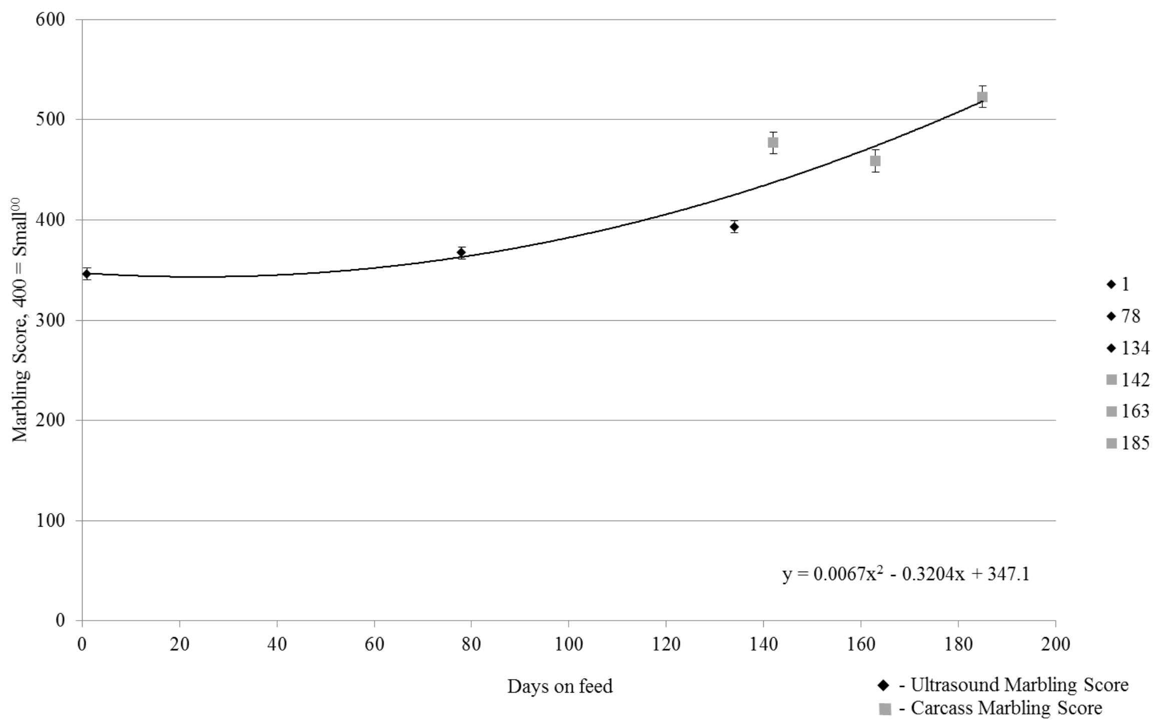

Figure 4. Marbling score of steers throughout days on feed. Days 1, 78, and 134 were measured using real-time carcass ultrasound on 2 pens of cattle (n = 76). Ultrasound measurement was evaluated as percent intra-muscular fat and converted to marbling score (Wilson et al., 1999a) which was averaged. Marbling score for days 142, 163, and 185 was evaluated at time of harvest for each serial slaughter group (38 steers) and averaged. Marbling score quadratically increased (P < 0.01) from d 1 at 346 to 526 at 185 days on feed.

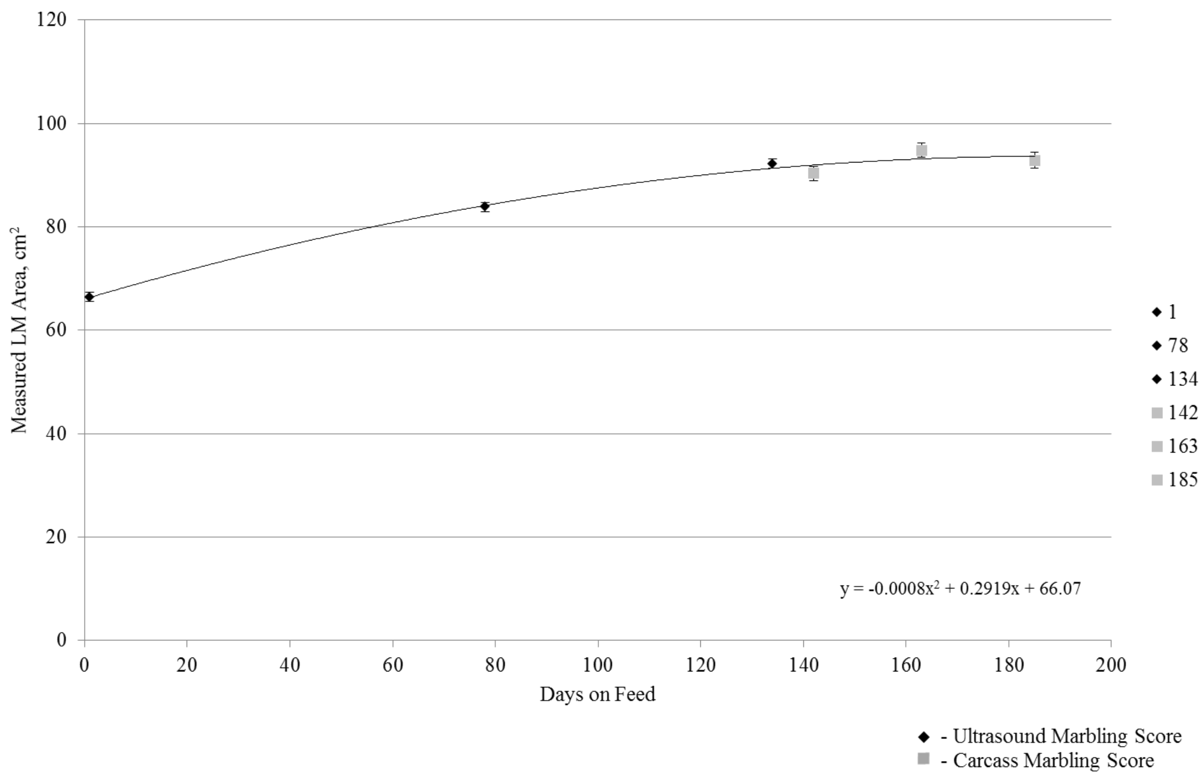

Figure 5. Measured LM area (cm^2) throughout days on feed. Days 1, 78, and 134 were measured using real-time carcass ultrasound on 2 pens of cattle (n = 76) and averaged. Days 142, 163, and 185 were measured at time of harvest for each serial slaughter group (38 steers) and averaged. Steer LM area increased quadratically ($P < 0.01$) from 66.5 cm^2 at d 1 to 92.3 cm^2 at 185 days on feed.

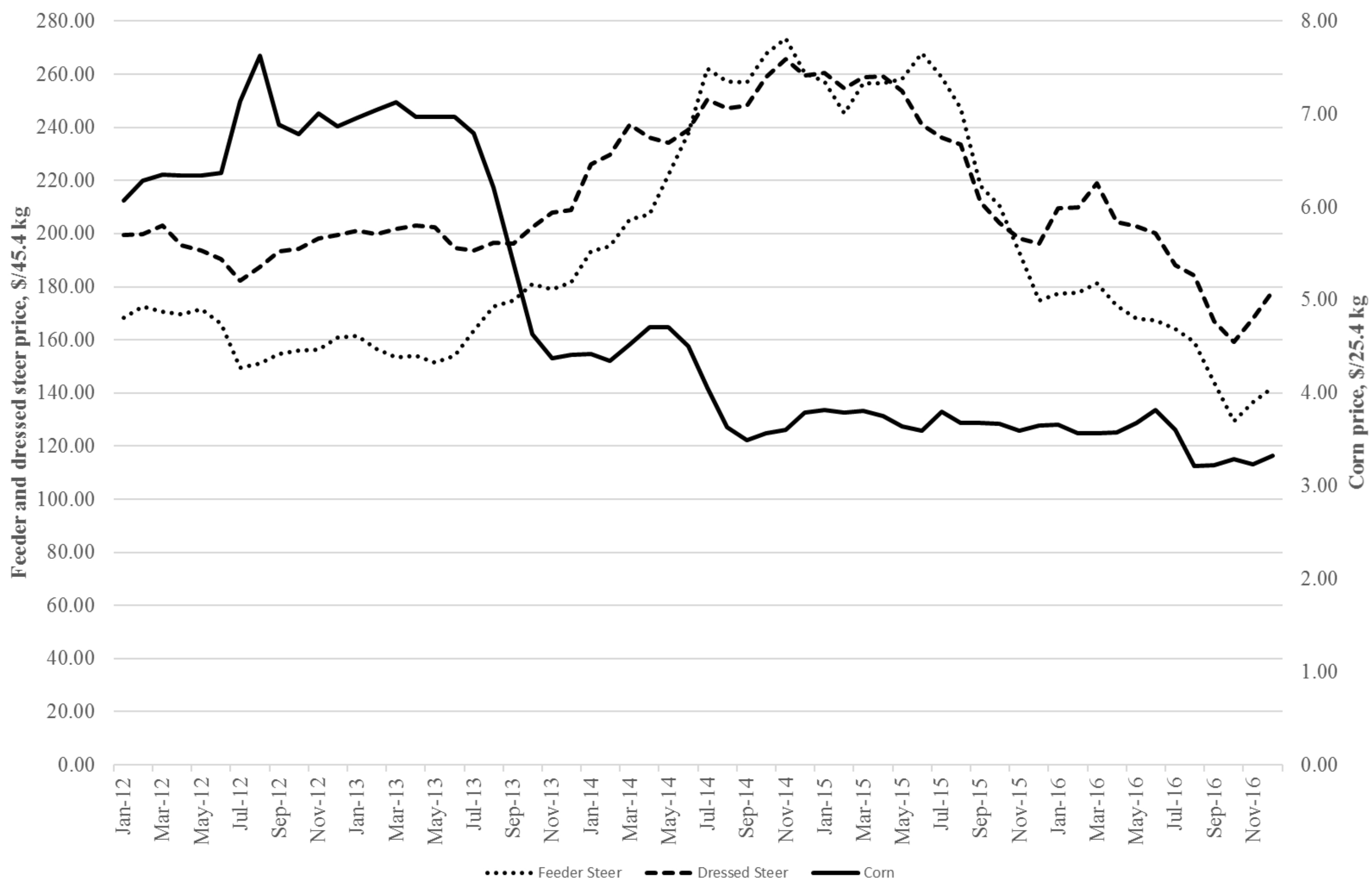

Figure 6. Monthly average feeder steer (dotted line, primary y-axis), dressed steer (dashed line, primary y-axis), and corn (solid line, secondary y-axis) price per month from January 2012 to December 2016.

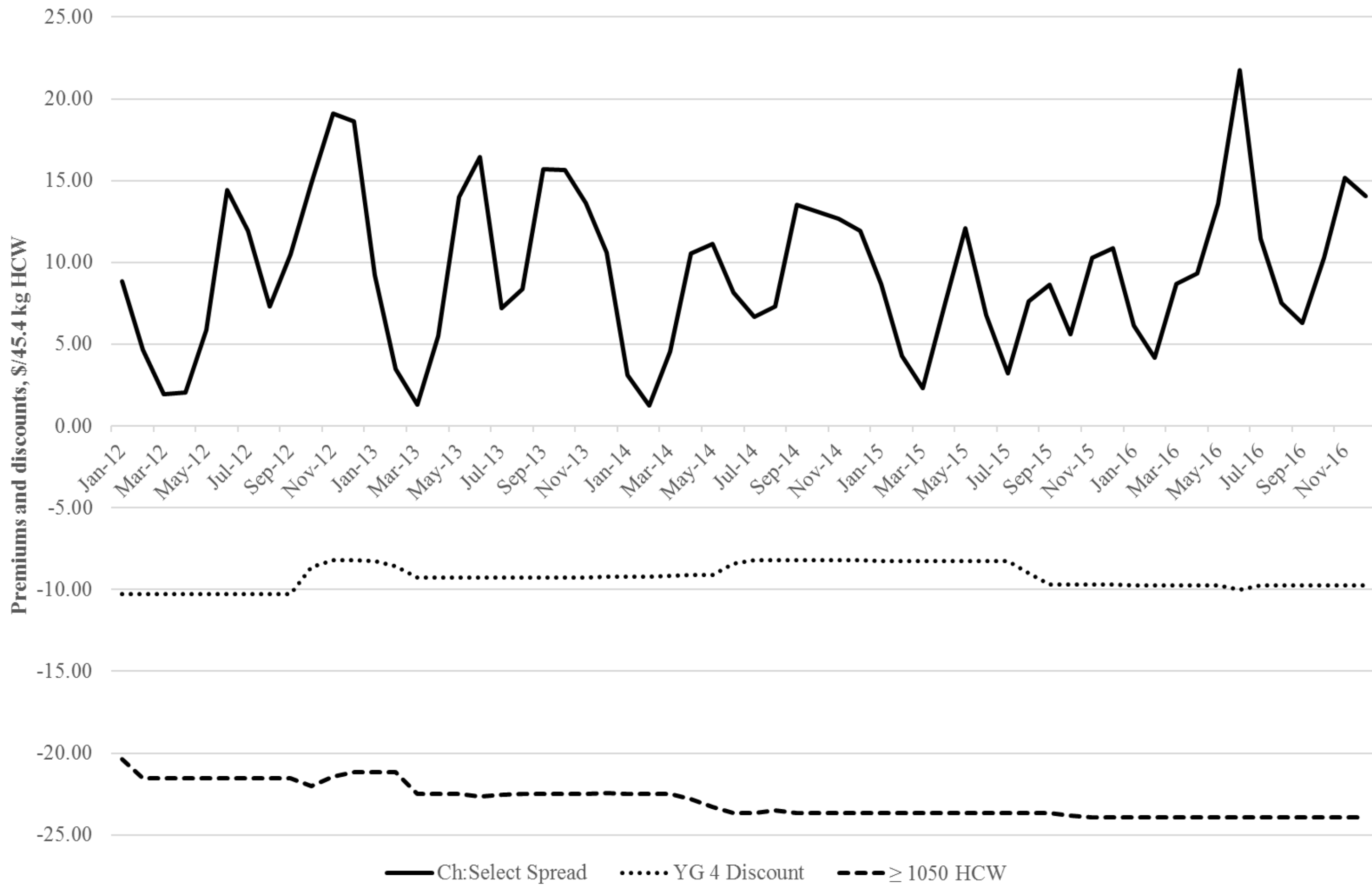

Figure 7. Monthly average Choice:Select spread (solid line), yield grade 4 discount (dotted line), and discount for HCW ≥ 477 kg (dashed line) from January 2012 to December 2016.